ENVIRONMENTAL CONTAMINANTS IN AQUATIC PLANTS, INVERTEBRATES, AND FISHES OF THE SAN JUAN RIVER MAINSTEM, 1990-1996

Prepared for the San Juan River Recovery Implementation Program

by

Zachary R. Simpson and Joel D. Lusk

U. S. Fish and Wildlife Service
New Mexico Ecological Services Field Office
Environmental Contaminants Program
2105 Osuna Road NE
Albuquerque, New Mexico 87113
(505) 346-2525

October 26, 1999

ACKNOWLEDGMENTS

This environmental contaminant investigation was funded by the San Juan River Recovery Implementation Program, the Department of the Interior National Irrigation Water Quality Program, and the U.S. Fish and Wildlife Service Division of Environmental Contaminants. This investigation would not be possible without the field work and assistance of the U.S. Fish and Wildlife Service's New Mexico, Colorado, and Utah Ecological Services and Fishery Resources Field Offices. We were also grateful for the assistance and data contributions by the U.S. Geological Survey Water Resources Office in Albuquerque, the U.S. Bureau of Land Management in Farmington, Mr. Dale Ryden, the New Mexico Department of Game and Fish, the U.S. Bureau of Indian Affairs, the Navajo Nation, the U.S. Bureau of Reclamation, New Mexico State University, and Keller-Bliesner Engineering, Inc. Welcome reviews were provided by Brian Hanson, Rob Ashmen, and Steve Hamilton.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES ~*Continued*

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION / EXECUTIVE SUMMARY

The San Juan River Recovery Implementation Program ("SJRIP") was initiated in October 1991. The SJRIP's goals are to: a) recover the endangered fish in the San Juan River Basin, and b) accommodate the needs of future water development in the San Juan River Basin. The San Juan River provides habitat essential to the survival of two fishes in danger of extinction: the Colorado pikeminnow (*Ptychocheilus lucius*) and the razorback sucker (*Xyrauchen texanus*). The SJRIP funded investigations of the physical, chemical, and biological characteristics of the San Juan River mainstem environment. The SJRIP Biology Committee identified environmental contamination of river sediment, biota, and water quality, as important aspects of San Juan River to be investigated during the 7-year research period (1991-1997). From 1993 to 1994, the SJRIP funding studies on water quality (Abell 1994a). From 1994 to 1996, the SJRIP funded an environmental contaminant investigation of aquatic plants, invertebrates and fish collected from the San Juan River mainstem (this "Synoptic Study").

The objectives of this Synoptic Study were:

Objective 1. Survey and report environmental contaminants in aquatic plants and animals of the San Juan River mainstem to reflect and identify any sources of pollution or harmful conditions.

During the 7-year research period, several collections were made of plant and animal tissues for chemical analyses in order to interpret the concentrations given threshold criteria, and determine seasonal, species, and spatial variations, among other factors. Additional samples were collected under the Department of the Interior's National Irrigation Water Quality Project (Blanchard et al. 1993, Thomas et al. 1998). Data generated from these sampling events were combined and then contaminant trends in biota by river reach and species were identified or used as indicators of potential contaminant sources. Contaminant concentrations in biota were also compared with literature values where the potential for harm was identified.

The Synoptic Study included 19 sites for extensive sampling of submergent plants, aquatic invertebrates, and fish from mainstem and backwater habitats of the San Juan River. Semipermeable membrane devices were also deployed at 10 sites in order to detect the presence of petroleum pollution and its by-products in the San Juan River. The Synoptic Survey was completed in Fall 1995 and the results were reported in the SJRIP's Annual Report (Wilson et al. 1995). Wilson et al. (1995) evaluated contamination (both inorganic and organic) in the San Juan River from the Navajo Reservoir in New Mexico to the San Juan River arm of Lake Powell in Utah. However, few samples were collected west of Four Corners, New Mexico. Furthermore, only three backwaters along the San Juan River were sampled, thereby reducing the ability of this Synoptic Study to determine the differences in contaminant concentrations between biota taken from backwaters and biota taken from the mainstem. Unfortunately, this aspect also limited the interpretation of the effects of contaminants to animals that reside or consume food predominantly from backwaters, such as the razorback sucker and Colorado pikeminnow.

Given existing data, two classes of environmental contaminants have been identified that have the potential to pose health risks to fish and wildlife of the San Juan River, namely, trace elements and polynuclear aromatic hydrocarbons (PAHs). Of the 21 elements analyzed, six were selected in this report for further evaluation based on several selection criteria, such as the frequency of detection, the availability of a threshold concentration, and likelihood of harm, and they were aluminum, arsenic, copper, mercury, selenium, and zinc. Areas where trace elements could pose the greatest potential for harm to the endangered fishes (and other wildlife) included the upper reaches of the San Juan River and off-channel habitats such as the mouths of tributaries and irrigation return drains.

The general health of the San Juan River fish community was investigated by Hart and Major (1995) after reports of lesions were reported by Blanchard et al. (1993) as well as fishery biologists. A 2.7% overall incidence of abnormalities (lesions, deformities, tumors, parasites, etc.) was reported in fish sampled from 1992 to 1994. The majority of fish with abnormalities were flannelmouth suckers (*Catostomus latipinnis*). The incidence of spinal deformity in adult flannelmouth suckers was about 0.3%. The greatest incidence of abnormalities in flannelmouth suckers occurred in River Reach 6.

Blanchard et al. (1993), Wilson et al. (1995), and Thomas et al. (1997, 1998) reported on the incidence of organochlorine pesticide and polychlorinated biphenyl (PCB) contamination in the biota of the San Juan River Basin. Organochlorine pesticide residues were generally below the detection limit. Thomas et al. (1998) reported that no organochlorine pesticide residues or PCBs exceeded dietary threshold concentrations, but cautioned that PCBs represent a class of 209 chemicals with differing toxicities and this aspect was not taken into account. Individual PCB congeners have the potential to act as "rogue hormones" with adverse effects to biota even at extremely low concentrations below current detection limits (Hoffman et al. 1996).

Monitoring for PAHs has been conducted in water, soils, and sediments and PAHs have been found infrequently above the analytical detection limit (Odell 1997, Wirth 1999). The analyses of PAH residues in fish bile, eggs, and semipermeable membrane devices (so called "SPMDs") in air and water have indicated widespread PAH exposure as well as detectable residues in lipid containing materials such as animal fats (Odell 1997, Wirth 1999, H. Prest, Univ. California, written communication). However, indications of harm were either not evaluated or indicated consistently (Wilson et al. 1995, Allert et al. 1999). Areas where PAHs could pose the greatest potential for harm to the endangered fishes (and other wildlife) included the Animas River and the San Juan River near Bluff, Utah, and Zahn Bay in Lake Powell.

Objective 2. Identify any relationship between environmental contamination and the research flow regime of the San Juan River.

During the 7-year research period, the responses of fish and their habitats to manipulation of flow discharge from the Navajo Dam were gathered and evaluated (Holden 1999). This Synoptic Study evaluated the relationship between different flow regimes and contaminant concentrations in biota from eight reaches of the San Juan River. Methods and results were similar to those presented by Holden (1998) that evaluated waterborne or invertebrate contaminant concentrations with instream flow discharge. Using stream flow data from United States Geological Survey (USGS) gaging stations, flow data were compared to contaminant data from biota collected from the San Juan River in order to discern relationships. No consistent correlations were found.

Objective 3. Identify potential contaminants of concern to the endangered fish and monitor environmental contaminants in the endangered fish using nonlethal methods.

The SJRIP arranged toxicity tests to determine the effects of environmental contaminants in water (Hamilton and Buhl 1997), and in diet and tissues (Buhl and Hamilton 1998) of the razorback sucker and Colorado pikeminnow. The waterborne toxicity tests showed a potential threat to endangered species from waterborne concentrations of selected contaminants, namely copper and mixtures simulating the water quality conditions of two irrigation drains (Hamilton and Buhl 1995, 1997). The results of the dietary toxicity test and accumulation study, however, were equivocal and such a study should be replicated as it is extremely important to their recovery.

A nonlethal environmental contaminant monitoring technique was initiated on razorback suckers in the San Juan River similar to a study in the Green River (Waddell and May 1995). Selenium was analyzed in 31 muscle plugs taken from razorback suckers introduced and four Colorado pikeminnow collected from the San Juan River. The results were provided in this report. Other than comparisons to concentrations in fish sampled nationwide, interpretation was limited until further studies identify toxicological effects with muscle concentrations in the endangered fish. Given the lack of other empirical data, such as the collection and chemical analyses of ovary tissue (the indicator tissue of selenium's adverse effects), however, the authors chose to predict the concentrations of selenium expected in endangered fish' ovarian tissue from the selenium concentrations found in their muscle or whole body, and then predicted potential harm. Essential habitats (e.g., slackwater areas) for the razorback sucker were not sufficiently sampled by this Synoptic Study to quantitatively estimate the risks there or robustly determine differences in environmental contamination compared with other habitats.

Objective 4. Develop a long-term monitoring plan of the environmental contaminants of concern to endangered species and provide a widely available environmental contaminants database.

Contaminant monitoring has been suggested to assess the direct dietary toxicity to endangered fish as a component of the recovery process. Previous studies have identified components of water pollution that would likely exhibit direct and indirect toxicity to the endangered fishes (Abell 1994, Hamilton and Buhl 1997, Allert et al. 1999, Wirth 1999). Contaminants of concern that were identified included: arsenic, copper, selenium, zinc (Wilson et al. 1995, Hamilton and Buhl 1995, 1997), as well as PAHs (Wilson et al. 1995). (Allert et al. (1999), also indicated the ultraviolet radiation may pose additional risks to biota in backwater habitats. Given this information, two data needs were identified that would be crucial towards developing the data quality objectives of a long-term environmental contaminant monitoring program:

- Quantify diet preference, feeding location, and the quality of prey used by various life stages of razorback sucker in the San Juan River.

- Quantify concentrations of selenium and toxicity thresholds for diet, egg, and muscle plug concentrations of the endangered fishes.

This report further identified areas in which more research was needed before the development of a basin- or agency-wide monitoring plan. The environmental contaminants data used and this report are proposed to be made widely available from the Fish and Wildlife Service internet website at the Universal Resource Locator:

http://southwest.fws.gov/sjrip/

METHODS

Sample Collection

Methods of sample collection were detailed in Blanchard et al. (1993), Wilson et al. (1995), and Thomas et al. (1997). In general, aquatic plants were grab sampled, picked clean of sediment and debris, rinsed in the field using either site water or deionized water, and frozen until shipment to an analytical laboratory. Invertebrates were sampled either by hand or using light traps. Whole body fish were collected using either standard electroshocking methods or seining. Some fish were filleted. All fish were bagged and frozen until shipment.

Methods of collection varied by personnel, however, and no one systematic method of sample collection or analysis was followed for all the samples. Methods of analysis, detection limits, and quality assurance and quality control varied given the contract laboratory used for a given study. All laboratory analyses were assumed to have been measured with negligible error.

Data Analysis and Statistical Methods

Data presented and evaluated were compiled from multiple sources. Aside from data collected specifically for this study (Wilson et al. 1995) data were also gathered from the National Irrigation Water Quality Program investigations of the San Juan River (Blanchard et al. 1993, Thomas et al. 1997), as well as biological and water chemistry data from Keller-Bliesner Engineering, Inc., and, biological, water, and sediment data from the Department of the Interior's 1996 Westwide Study (unpublished). In total, Appendix A contains environmental contaminant data for 759 biological samples, including 64 aquatic plant samples, 86 invertebrate samples, and 609 fish tissue samples collected from mainstem habitats of the San Juan River.

Environmental contaminant data were collected from the "mainstem" portion of the San Juan River (and its associated backwaters, slackwaters, tributary mouths), and not, for example, from other off-channel aquatic habitats in the basin (e.g., nearby upland ponds, in upstream tributaries). Environmental contaminant data for sites associated with Department of the Interior irrigation projects were evaluated in Blanchard et al. (1993) and Thomas et al. (1998). Much of the data collected for the Synoptic Study were compiled to assess environmental contamination of aquatic invertebrates and fish, because they might coexist with, or be utilized by the endangered fish. Ryden (1995a, 1995b) and Miller (1995) reported that endangered fish tend to use slack- and backwater habitats as staging grounds for spawning, feeding, and the rearing of young, but such habitats were rare on the San Juan River (Bliesner and Lamarra 1995), and few were adequately sampled along the San Juan River mainstem during this Synoptic Study.

Data were reported in either dry weight (DW) or wet weight (WW) concentrations and were so indicated. To convert dry weight concentrations into wet weight concentrations, the following equation can be used:

$$\text{Wet weight} = (\text{Dry weight}) \times [1 - (\text{percent moisture}/100)]$$

In some cases, after conversion to wet weight concentrations, fish that had fillets removed were mathematically “re-integrated” (as the sum of weighted concentrations of the parts of a fish) to yield an ‘integrated’ whole body fish concentration, thereby allowing whole body comparisons of contaminant concentrations with those in integrated whole body fish. A generalized equation was used to calculate integrated fish contaminant concentration (Equation 2, below).

Equation 2. Equation Used to Reintegrate Fillets with Remaining Partial Body Fish

$$\text{Integrated fish concentration} = [(fM/wM) \times cF] + [(pM/wM) \times cP]$$

where:

fM	mass of a fillet (g)
wM	whole body mass = mass of fillet + mass of partial body (g)
cF	contaminant concentration in a fillet (mg/kg)
pM	mass of partial body (g)
cP	contaminant concentration in partial body (mg/kg)

example:

Given:

fM = 20 g
pM = 180 g
wM = fM + pM = 200 g
cF = 0.5 mg/kg
cP = 2.8 mg/kg

Then:

integrated fish concentration
= ((20g/200g) x 0.5mg/kg) + ((180g/200g) x 2.8mg/kg)
= 2.57 mg/kg

Each sample was classified according to its general site description (e.g., in the Mixer, near Kutz Canyon, etc.), its latitude and longitude, river mile (some of the river mile location information was either inaccurate or not provided; thus, a variety of sources were used in order to standardize the river mile designation), and hydrologic unit (Appendix B). The data were then categorized into one of eight geomorphic river reaches as determined by Bliesner and Lamarra (1993, 1994, 1995) (see Figure 1). Samples were also categorized by taxonomy, flow, date, and habitat type (Appendix C). Most samples were composites rather than individuals.

For statistical purposes and simplicity, all results, including integrated fish, which were below the laboratory's instrument detection limit, were replaced with a value one-half the instrument detection limit (USEPA 1998). Additionally, data were natural log transformed to normalize the data distribution prior to parametric statistical tests (Bailey 1981) including a one-way analysis of variance (ANOVA).

Several descriptive statistics (e.g., the geometric mean) and analyses (e.g., regression, principal component analyses) were conducted on concentrations of selected contaminants in biota. The software program called STATISTICA (StatSoft Inc. 1994) was used on a personal computer. The Multiple Regression Module of STATISTICA (StatSoft Inc. 1994) was used to analyze the relationship between selected contaminants in biota and flow. Multiple regression with few variables was unnecessary and in this case the software defaulted to a linear regression of flow with contaminant concentrations in biota.

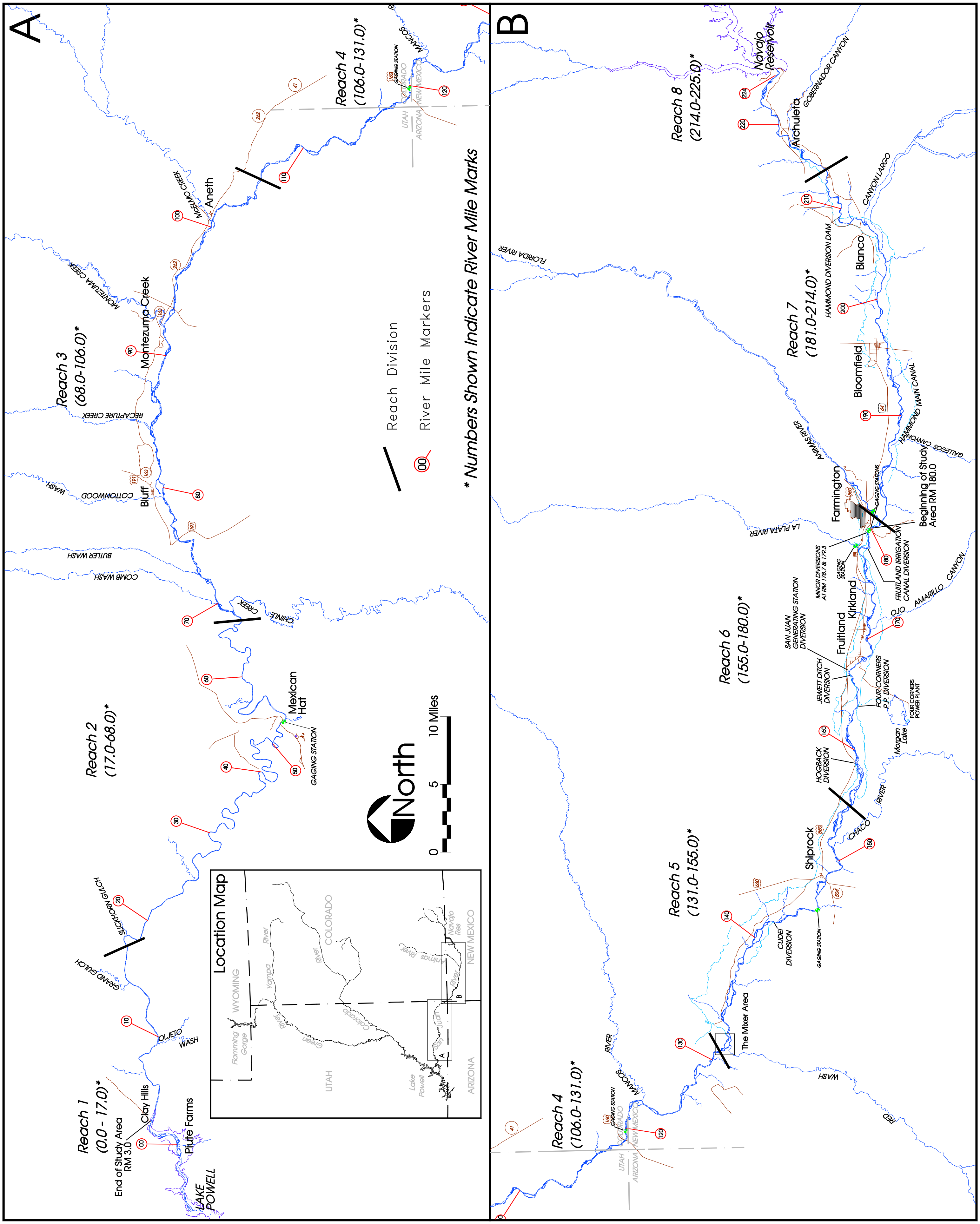


Figure 1. San Juan River Recovery Implementation Program Study Area.

Geometric means were calculated in both dry and wet weight concentrations for selected environmental contaminants. The geometric mean was provided as a measurement of the central tendency of contaminant distributions that was resistant to the effects of outliers and was calculated using data converted to their natural logarithms. However, when only one sample was collected for a reach, then that value was directly reported in tables and appendices as the geometric mean with the sample number identified as one.

Natural-log transformed data were also used during statistical tests between selected biota by reaches, species, and matrices. Natural-log transformed dry weight data were used in the ANOVA significance testing with Tukey's test for Honestly Significant Differences ($p \leq 0.05$) (StatSoft Inc. 1994). Varimax normalized principal components analysis was also performed using non-natural log transformed dry weight concentrations (StatSoft Inc. 1994). The number of factors was determined by a visual evaluation of a scree plot.

Environmental contaminant concentrations were evaluated using three techniques:

1. Concentrations in San Juan River biota were compared to values reported in the literature as ambient or elevated in biota.

2. Environmental contaminant concentrations in San Juan River biota were also compared groupwise, according to the methods described by Velz (1984) and Carter (1997). To date, no regional studies of the background concentrations of trace elements in biota from the San Juan River have been reported from which to identify elevated concentrations. Therefore, for each trace element evaluated, cumulative frequency curves were plotted for the concentrations in plants, invertebrates, and fish collected. For these distributions, the first point of substantial change in concentration was considered regionally elevated. Rather than use visual observation, which often corresponded with the 95th percentile value, the 95th percentile value was identified as the concentration above which sample concentration was considered elevated. National studies often identify concentrations above the 85th percentile value as regionally elevated (e.g., Schmitt and Brumbaugh 1990). For the Synoptic Study, all values above the calculated 95th percentile value were considered regionally elevated and were evaluated for site, river reach, or species trends. This method will be referred to as the Regional Comparison Method (RCM).

3. Contaminant concentrations were compared to concentrations reported in the literature to be associated with harm to an individual or a population. These concentrations were considered threshold criteria and were referenced.

Flow Considerations

Following the methods of Holden (1998), each sample collected for the Synoptic Study was matched to the instantaneous flow reported at the nearest USGS gage station for the river reach and the date in which the sample was collected. Flow measurements for the period between January 1, 1990, and September 30, 1996, were obtained from the USGS historical streamflow website at http://waterdata.usgs.gov/nwis-w/US/. Discharge was calculated from the five San Juan River gaging stations at Archuleta, Farmington, and Shiprock, New Mexico, at Four Corners, Colorado, and at Bluff, Utah. Gage stations were not available for each river reach, therefore, the measured discharge from the Archuleta station was used to approximate flow in River Reach 7 and River Reach 8; the discharge at Farmington was used for River Reach 6; the discharge measured at Shiprock was used for River Reach 5; the discharge at Four Corners was used for River Reach 4; and the discharge at Bluff was used for River Reach 1, River Reach 2, and River Reach 3. The Four Corners station accounts for the flow contribution of the Mancos River, a major tributary within River Reach 4. However, samples collected above the confluence of the Mancos River had the discharge contribution of the Mancos River subtracted from it to reflect the discharge at their collection.

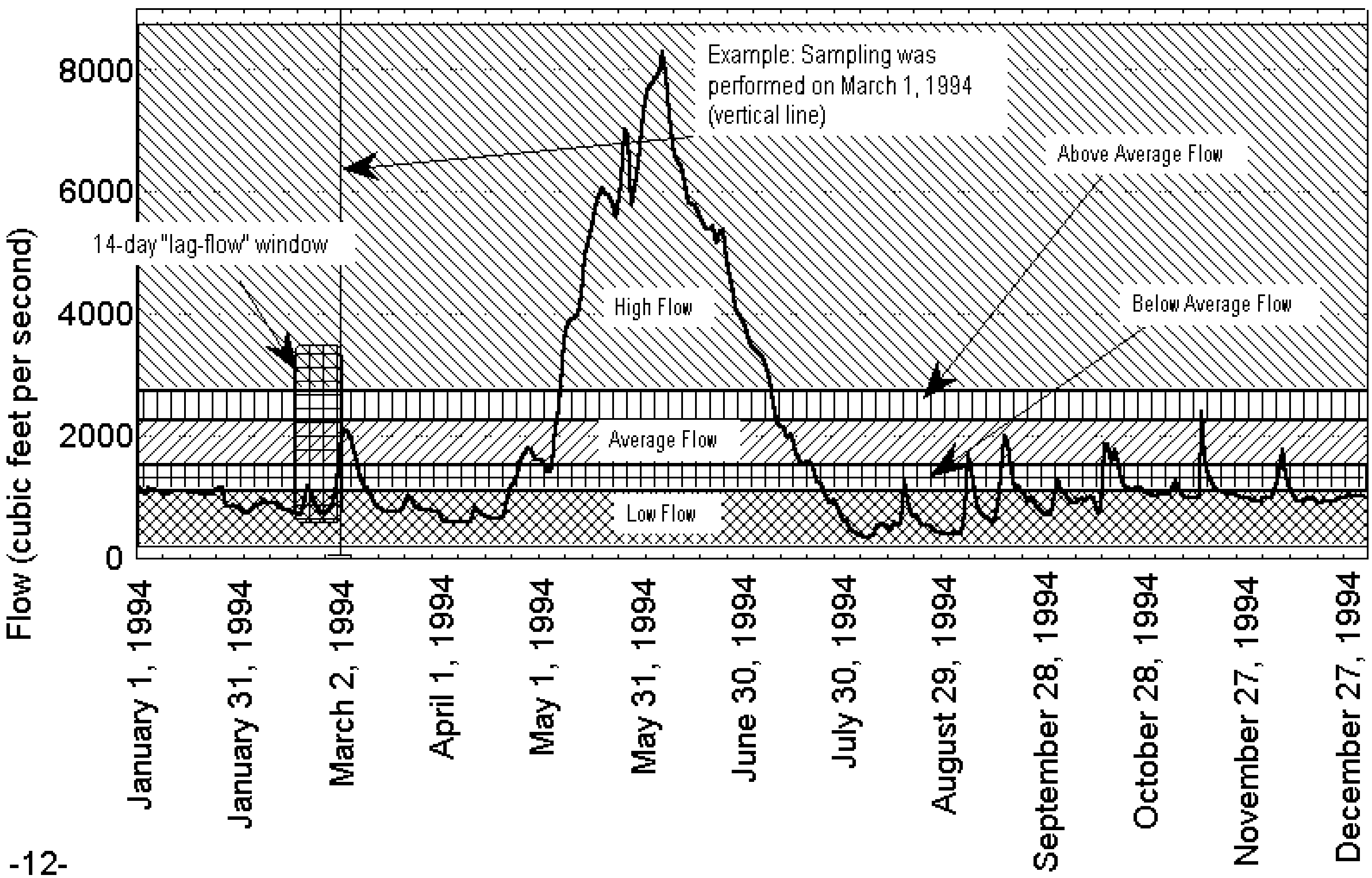
Discharge data were entered into a computer spreadsheet with each sample and they were assigned to five flow categories (low, below average, average, above average, and high) as well as two flow regimes (instantaneous flow and lag flow) (Appendix C). Figure 2 presents an example of the flow regimes and categorization corresponding to a sample collection performed on March 1, 1994. Each sample collected was associated with the average instantaneous flow in the San Juan River reach on the day of collection. Also, the average instantaneous flow 14 days prior to sample collection was determined for each sample ("lag-flow"). Lag flow was calculated based on the hypothesis that contaminant accumulation might be delayed from exposure prior to collection. For example, Finley (1985) and Coughlan and Velte (1989) reported that selenium accumulation in biota reflected past dietary exposure; therefore, discharge was evaluated with instantaneous flow at collection or the lag flow two weeks prior to collection, with contaminant body burdens of arsenic, copper, selenium and zinc. Discharge measurements were also assigned a flow category. Flow categories were determined using percentile summaries of all flow measurements in each river reach from 1990 to 1996. Each flow category is presented in Table 1 along with the number (N) of samples collected. Note that the timing of samples collection was not concordant with the different flow categories, and therefore sample collection was not distributed evenly among the different flow categories.

Table 1. Sample Collection Distribution by Instanteous Flow Category and River Reach for the San Juan River, 1990-1996.

RIVER REACH[1]	FLOW CATEGORY[2]	LOWER BOUND (CFS[3])	UPPER BOUND (CFS[3])	N[3]	Percentage of Samples Collected from a Reach for Flow Category
River Reach 1	Low	0	841	4	14.8
	Below Average	841	1120	15	55.6
	Average	1120	1950	8	29.6
River Reach 2	Below Average	841	1154	12	100
River Reach 3	Below Average	841	1120	38	86.4
	Average	1120	1950	6	13.6
River Reach 4	Below Average	844	1100	14	63.6
	Average	1100	1986	8	36.4
River Reach 5	Low	0	795	7	6.7
	Below Average	795	1060	60	57.1
	Average	1060	1862	30	28.6
	High	1990		8	7.6
River Reach 6	Low	0	831	43	24.6
	Below Average	831	1060	38	21.7
	Average	1060	1923	46	26.3
	Above Average	1923	1930	1	0.6
	High	1930		47	26.9
River Reach 7	Low	0	534	30	14.0
	Below Average	534	606	63	29.3
	Average	606	798	26	12.1
	Above Average	798	1114	28	13.0
	High	1114		68	31.6
River Reach 8	Low	0	534	23	14.5
	Below Average	534	606	3	1.9
	Average	606	798	93	58.5
	High	1114		40	25.2

1 - River Reach designation range based on Figure 1.
2 - Flows categorized as: Low (minimum - 25th percentile); Below Average (25th percentile - median); Average Flow (median - mean); Above Average (mean -75th percentile); and High (75th percentile - maximum).
3 - CFS= cubic feet per second; N= number of samples collected in the flow category.

Figure 2. Hydrograph of River Reach 3 in 1994 Presenting Evaluation of Instantaneous and 14-Day Lag Flow During Sample Collection.



Holden (1998) evaluated the correlation between flow discharges and concentrations of environmental contaminants in water and invertebrates of the San Juan River. Similar techniques were employed in this report to evaluate the relationship between flow measurements (instantaneous and lag flow) and environmental contaminant concentrations in plants, invertebrates, and whole body fishes.

A correlation matrix with selected contaminants of concern (arsenic, copper, selenium, and zinc), the lag flow, and river miles was generated in order to distinguish any general trends. Linear regression was used to evaluate lag flow correlations with concentrations of arsenic (Appendix D-1), copper (Appendix D-2), selenium (Appendix D-3), and zinc (Appendix D-4) in San Juan River biota.

Endangered Fish Muscle Plugs

In order to assess selenium contamination of endangered fish using a non-lethal method, Colorado pikeminnow and razorback sucker muscle plugs were opportunistically sampled during fish surveys of the San Juan River by the U.S. Fish and Wildlife Service, Fishery Resources Office, Grand Junction, Colorado. Muscle plugs were collected anterior to the dorsal fin of the fish, placed in sample containers, and frozen in the field until analysis according to methods detailed by Waddell and May (1995). Additionally, three whole body razorback sucker samples were collected in October 1995.

All razorback sucker muscle plugs were collected from fish that had been introduced into the San Juan River for approximately one year, however, each individual fish was not re-sampled, but a cohort from the same group was sampled after one year. Six razorback sucker muscle plugs were collected prior to stocking to determine pre-San Juan River exposure concentrations of selenium in the muscle tissue. All introduced fish were outfitted with Passive Integrated Transponder (PIT) tags prior to stocking in the San Juan River. All Colorado pikeminnow muscle plugs were collected from wild fish.

Razorback sucker and Colorado pikeminnow data are presented in Table 2. Due to analytical requirements of amount of tissue, muscle plugs were only analyzed for selenium. The PIT tag number, location of recapture, introduction date, recapture date, weight, length, and concentration of selenium are included in Table 2.

Table 2. Razorback Sucker and Colorado Pikeminnow Selenium Concentrations (µg/g, Dry Weight) in Whole Body and Muscle Plug Samples Collected from the San Juan River in Utah, Colorado, and New Mexico.

River Mile	Sample Identification Code	PIT Tag Number	Location of recapture	River Reach	Introduction Date	Recapture Date	Weight (g)	Total Length (mm)	Se µg/g, DW
Whole Body Razorback Suckers									
120	SJRRBS03	1F733C783A	Four corners	4		October 3, 1995	800	439	3.8
135	SJRRBS02	1F733C535F	Above the mixer	5		October 5, 1995	625	427	4.3
151	SJRRBS01	1F41394126	Above Shiprock	5		October 6, 1995	870	442	3.8
Razorback Sucker Muscle Plugs									
54.1	SJRZ12	1F732D724F	Above Mexican Hat Boat	3		October 3, 1995	790	424	3.9
62	SJRZ20	1F41505779	Below Chinle Creek	2		October 5, 1995	675	414	4.3
72.1	SJRZ11	1F43686353	Recaptured below Cottonwood	3		October 6, 1995	790	427	3.6
79.6	SJRZ10	1F43686353	Stocked below Cottonwood	3		October 7, 1995	930	427	3.3
79.6	11270	7F7D171A43	Below Cottonwood wash	3		October 9, 1995	304	289	3.3
79.6	11269	7F7D22491A	Baseline	3	March 30, 1994		345	306	2.9
82	SJRZ19	1F435D1C25	Baseline	3	March 29, 1994		850	422	4.4
87.3	SJRZ18	1F742E4D72	Baseline	3	March 29, 1994		765	411	4.7
87.6	SJRZ9	1F40326B04	Baseline	3	March 29, 1994		635	364	3.7
93	SJRBMP05	1F40496870	Baseline	3	March 29, 1994		585	408	4.8
93.9	SJRZ8	1F41405A06	Below Montezuma Creek	3	Nov. 16, 1994	March 9, 1995	750	419	4.3
94.2	SJRZ21	1F685A1C03	Above Montezuma Creek	3	Nov. 16, 1994	May 8, 1995	130	231	1.1
102.5	SJRZ17	1F404E666D	Above McElmo	3	Nov. 18, 1994	May 8, 1995	600	372	4.7
108	SJRZ16	1F40496870	Below Mancos River	4	Nov. 18, 1994	May 9, 1995	720	408	3.2
110.7	SJRZ15	1F4040075A	Below Mancos River	4	Nov. 16, 1994	May 10, 1994	950	442	3.8
113	SJRBMP04	1F731C2E24	Below Mancos River	4	Nov. 18, 1994	May 10, 1994	510	411	5.4
116	SJRZ7	1F7441614B	Below Mancos River	4	Nov. 18, 1994	May 11, 1995	510	390	3.7
117.5	11267	7F7D224E24	Below Mancos River	4	Nov. 18, 1994	May 11, 1995	200	252	3.2
117.5	11268	7F7D1D4E7D	Below Mancos R. Confluence	4	Nov. 18, 1994	May 11, 1995	169	239	3.5
120	SJRBS03	1F733C783A	Four corners	4	Nov. 18, 1994	May 11, 1995	800	439	4.9

Table 2. Razorback Sucker and Colorado Pikeminnow Selenium Concentrations (µg/g, Dry Weight) in Whole Body and Muscle Plug Samples Collected from the San Juan River in Utah, Colorado, and New Mexico.

River Mile	Sample Identification Code	PIT Tag Number	Location of recapture	River Reach	Introduction Date	Recapture Date	Weight (g)	Total Length (mm)	Se µg/g, DW
122	SJRZ6	1F402D165E	Above Four corners	4	Nov. 18, 1994	May 12, 1995	750	404	11.0
123	SJRZ5	1F733D0031	Above Four corners	4	Nov. 18, 1994	May 12, 1995	525	376	4.0
123	SJRZ14	1F43596560	Above Four corners	4	Nov. 18, 1994	May 12, 1995	600	388	4.7
126	SJRZ13	1F41401050	The Mixer	4	Nov. 18, 1994	May 13, 1995	800	427	4.2
129.9	SJRZ4	7F7D164D53	The Mixer	4	Nov. 18, 1994	May 13, 1995	120	244	1.2
135	SJRBS02	1F733C535F	Above the mixer	5	Nov. 18, 1994	May 13, 1995	625	427	4.5
136.6	11266	7F7D22532E	Above the mixer	5	Nov. 18, 1994	May 14, 1995	290	289	3.2
137.2	SJRZ3	1F40735A54	Above the mixer	5	Oct. 27, 1994	May 15, 1995	750	420	4.4
151	SJRBS01	1F41394126	Baseline	5	Oct. 27, 1994		870	442	4.9
156.5	SJRZ2	1F404F4A08	Above Shiprock	6	Nov. 18, 1994	May 16, 1995	630	388	4.3
158	SJRZ1	7F7D177124	Above Shiprock	6	Nov. 18, 1994	May 15, 1995	450	356	3.1
Colorado Pikeminnow Muscle Plugs									
74.8	11273	7F7D075651	Below Cottonwood wash	3	wild fish capture	April 15, 1994	3900	753	2.9
123.6	SJCSMP	1F74387F36	Four corners	4	wild fish capture	October 3, 1993	4370	823	3.3
129.2	11272	7F7D225E24	The Mixer	4	wild fish capture	October 8, 1993	5510	820	2.9
133.2	11271	7F7D077A18	The Mixer	5	wild fish capture	October 5, 1993	2000	617	3.9

See Figure 1 for River Reach and River Mile location
"Baseline" indicated sample collection (from hatchery stock) prior to introduction into San Juan River
PIT = passive integrated transponder
g = grams
mm = millimeters
Se = selenium
DW = Dry Weight

RESULTS AND DISCUSSION

Flow Considerations

No consistent river-wide or reach-wide correlations were detected between lag flow and the concentrations of arsenic (Appendix D-1), copper (Appendix D-2), selenium (Appendix D-3), and zinc (Appendix D-4) in plants, whole fish, or aquatic invertebrates. Although not presented, similar results were found for instantaneous flow and contaminant concentrations in biota. As an example, when discharge was above average for a river reach, the corresponding biological samples collected did not contain contaminant burdens consistently higher than in samples collected during below average flow. Occasionally, arsenic concentrations in plants correlated with instream lag flow (Appendix D-1) in some reaches, while copper concentrations in invertebrates from River Reach 5 and zinc concentrations in whole body fish from River Reach 3 and River Reach 5 were correlated (r^2>0.75) with lag flow. The occurrences of environmental contaminant concentrations in aquatic plants, invertebrates, and whole body fish of the San Juan River, therefore, were likely dependant upon other factors (i.e., site- and species-specific factors) than flow *per se*.

The Synoptic Study did not evaluate water quality trends or examine differences in contaminant body burdens in aquatic life from San Juan River backwaters during different flow regimes. Backwaters along the river could become shallow due changes in flow, recharge rates, and water levels. And such changes would undoubtedly alter the physical/chemical environment, habitat conditions and nutrient cycling (Stumm and Morgan 1970, Kennedy 1979, Holden et al. 1986, DeCamps and DeCamps 1989, Allen 1991, Presser 1994). Reduced flow in backwater habitats fosters the deposition of suspended materials that can result in reduced turbidity, increased light penetration of the water column, increased temperature, changes to acidity, alkalinity, dissolved oxygen and nutrient cycling, as well as changes to the type, amount, and distribution of living and dead vegetation, wildlife abundance and diversity as compared with mainstem habitat. Research should continue to be directed toward understanding habitat quality alterations of backwaters, slackwaters, and flood plain habitats related to changes in the river hydrograph and water level.

Aluminum

Data Comparisons

Aluminum concentrations for each sample analyzed are reported in Appendix A. The number of samples, geometric mean, and range of aluminum concentrations were summarized by river reach, sample type, and species in Appendix E. The geometric mean aluminum concentrations in plants (Table 3), invertebrates (Table 4), and fish (Table 5) were compared with the other contaminants for mainstem and backwater habitats. The geometric mean aluminum concentration for each sample type and fish species are evaluated by river reach in Table 6. Summary findings regarding aluminum including data comparisons and a hazard assessment are found in Table 7.

The highest geometric mean concentration of aluminum in plants occurred in River Reach 7 and the lowest in plants was from River Reach 8, below Navajo Reservoir. Aluminum concentrations in plants increased tenfold between River Reach 8 and River Reach 7. Allert et al. (1999) found differences in increased turbidity and temperature in River Reach 8 compared to River Reach 7. Biota in River Reach 7 were exposed to a increased suspended sediment compared with the cool, clear-water, reservoir releases found in River Reach 8. As aluminum is commonly associated with the mineral content in soils in sediments (Sparling and Lowe 1996), the increased exposure of plants to increasing suspended sediments downstream could account for the higher residues found in plants in downstream reaches.

Aluminum and several of the other transitional metals (iron, nickel, vanadium, chromium, lead, magnesium) as well as boron and arsenic had similar trends in biota. Using principle components analysis, a single factor can explain the 80% of the variability of these elements in plants, invertebrates, and fish (Figure 3). This factor might be related to soil and sediment quality in the basin. Principle components analysis does not identify what the factor was. The environmental contaminant burdens in biota of aluminum, iron, nickel, vanadium, chromium, lead, magnesium, boron and arsenic, then, likely reflect the ambient geochemical environment. Therefore, these elements may be governed in biota more by edaphic factors (i.e., biota reflect the ambient geology) as opposed to species-specific factors or point-source pollution.

Sparling and Lowe (1996) suggested that aquatic plants containing greater than 1000 µg Al/g DW were "accumulators," and plants containing greater than 5000 µg Al/g DW were "hyper accumulators." Hyper accumulators of aluminum were often species of algae or bryophytes. Many plant samples collected in the San Juan River contained algae (e.g., periphyton) and elevated aluminum concentrations. However, the methods of collection used may also have allowed the entrapment of sediment in the sample, thereby biasing aluminum concentrations in these plant tissues. Therefore, it was undetermined if the elevated aluminum concentrations detected were incorporated into tissues or adhered sediment on plant samples.

The distribution of aluminum concentrations in aquatic plants (Figure 4), invertebrates (Figure 5), and fish (Figure 6) were plotted using the Regional Comparison Method (RCM). Three samples of algae collected at River Mile 225, 148, and 119, were above the 95th percentile value of 30,700 µg/g for aluminum in aquatic plants.

Three invertebrate samples were above the RCM 95th percentile value. Two invertebrate samples were annelids (aquatic worms), which were known to ingest sediment and bias aluminum concentration ranges (Beyer and Linder 1995). Concentrations of aluminum in invertebrates from River Reach 5 and River Reach 6 were significantly higher than invertebrates sampled in River Reach 8. Aluminum concentrations in invertebrates (<4 to 1,702 µg/g DW) were within the range specified by Sparling and Lowe (1996) as ambient (<24 to 37,800 µg/g DW) for invertebrates.

Sixteen whole body fish samples were considered regionally elevated (i.e., above the RCM 95th percentile value). Nine samples were sucker species, and the other were small fish (n=3), speckled dace (n=2), and red shiners (n=2). Whole body fish from River Reach 1 through River Reach 6 often had higher aluminum body burdens than whole body fish from River Reach 8. The majority of fish containing elevated aluminum were sucker species collected from River Reach 6. Aluminum concentrations were significantly less in fish collected upstream.

Table 3. Geometric Mean Concentrations (µg/g Wet Weight (WW), except Selenium, which is µg/g Dry Weight [DW]) of Selected Elements in Plant Tissue from the San Juan River by River Reach (See Figure 1) and Habitat Type (Backwater [B] or Mainstem [M]).

Habitat / Element	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6		Reach 7	Reach 8		All Plants (µg/g WW)
	M	M	M	M	M	M	B	M	M	B	
Selenium (DW)	0.92	0.90	0.86	1.04	0.70	0.82	0.67	0.58	1.12	0.92	0.86 DW
Aluminum	2837	4819	4511	6162	4919	3951	1553	4941	1059	417	1240
Arsenic	1.04	0.93	1.19	1.21	1.36	1.03	0.50	1.36	0.34	0.11	0.42
Barium	39.18	379.08	67.63	61.60	51.68	51.83	34.11	83.15	27.14	20.80	28.99
Beryllium	0.12	0.30	0.20	0.27	0.21	0.25	0.05	0.27	0.04	0.01	0.06
Boron	30.1	36.9	17.3	15.4	17.4	14.8	1.9	8.6	10.0	5.3	9.3
Cadmium	0.08	0.13	0.10	0.06	0.07	0.11	0.06	0.03	0.05	0.02	0.05
Chromium	2.64	5.02	3.66	4.86	3.94	3.12	0.81	3.70	0.99	0.30	1.19
Copper	3.13	8.38	5.03	5.47	4.73	3.94	2.13	3.78	1.95	1.10	2.43
Iron	1763	5589	3006	3719	3149	2330	1169	3382	806	260	996
Lead	1.30	4.25	2.58	3.17	2.81	4.30	1.83	2.22	1.25	0.47	1.16
Magnesium	967	1337	1069	1213	950	699	438	801	497	367	636
Manganese	89.7	119.9	111.9	197.7	200.5	452.9	246.2	275.4	100.6	111.2	120.2
Mercury	0.006	0.016	0.013	0.020	0.013	0.013	0.003	0.012	0.004	0.002	0.005
Molybdenum	0.35	0.81	0.26	1.00	1.00	1.00	0.05	1.00	0.09	0.06	0.12
Nickel	1.64	3.20	2.31	3.83	2.35	1.78	0.70	2.48	0.78	0.37	0.94
Strontium	59.5	47.4	66.2	74.5	63.3	70.8	20.8	20.2	15.6	19.7	35.8
Vanadium	4.77	13.24	7.35	9.09	7.47	5.53	2.12	7.50	2.19	0.60	2.18
Zinc	8.45	22.68	16.33	20.23	23.76	31.27	20.94	9.70	4.66	3.07	8.21

Table 4. Geometric Mean Concentrations (µg/g Wet Weight [WW], except Selenium, which is µg/g Dry Weight [DW]) of Selected Elements in Invertebrates from the San Juan River Categorized by River Reach (See Figure 1) and Habitat Type (Mainstem [M], Backwater [B], or Confluence with Named Tributary).

Habitat / Element	Reach 1	Reach 2	Reach 3		Reach 4		Reach 5	Reach 6		Reach 7	Reach 8		All Inverte-brates
	M	M	M	McElmo Creek	M	Mancos River	M	M	B	M	M	B	
Selenium(DW)	2.87	3.02	2.58	2.00	2.49	4.63	2.47	3.13	4.71	3.88	4.82	2.92	3.26
Aluminum	775	505	621	239	651	881	1033	1209	843	595	424	178	374
Arsenic	0.16	0.12	0.08	0.43	0.28	0.25	0.40	0.33	0.56	0.24	0.33	0.16	0.21
Barium	20.83	17.56	13.88	11.13	7.49	19.40	11.09	13.81	8.33	13.15	11.97	3.90	7.81
Beryllium	0.02	0.01	0.02	0.02	0.01	0.03	0.03	0.05	0.02	0.02	0.02	0.01	0.02
Boron	0.8	1.2	0.8	0.7	0.8	1.6	0.9	1.4	0.5	0.9	0.5	0.3	0.6
Cadmium	0.07	0.04	0.03	0.03	0.02	0.04	0.02	0.07	0.13	0.04	0.07	0.06	0.05
Chromium	0.93	0.73	0.25	2.26	0.44	1.42	0.54	0.42	0.66	0.41	0.38	0.18	0.34
Copper	15.63	11.65	5.11	32.09	5.28	15.36	5.68	6.18	4.69	4.03	3.04	4.24	4.82
Iron	438	295	395	121	405	454	600	741	659	403	330	140	290
Lead	0.36	0.26	0.31	0.09	0.37	0.32	0.44	1.13	1.27	0.33	0.48	0.12	0.30
Magnesium	543	458	393	908	346	550	396	401	284	357	256	218	323
Manganese	29.4	15.5	16.9	14.4	21.2	49.7	37.2	108.9	90.7	105.8	35.8	18.3	30.0
Mercury	0.023	0.019	0.021	0.043	0.010	0.005	0.010	0.018	0.012	0.026	0.011	0.019	0.015
Molybdenum	0.32	0.28	0.33	0.36					0.05		0.07	0.09	0.11
Nickel	0.66	0.30	0.37	0.69	0.39	0.68	0.69	0.54	0.41	0.47	0.45	0.15	0.33
Strontium	40.8	33.5	10.0	234.4	9.5	52.8	9.2	19.1	5.5	9.0	9.4	6.0	12.2
Vanadium	1.26	0.86	1.05	0.39	1.20	2.03	1.62	1.86	1.35	1.19	0.85	0.36	0.72
Zinc	38.24	26.89	44.47	26.57	36.07	18.51	43.96	45.57	33.74	25.03	10.80	16.18	22.39

Table 5. Geometric Mean Concentrations (µg/g Wet Weight [WW], except Selenium, which is µg/g Dry Weight [DW]) of Selected Elements in Whole Fish from the San Juan River Categorized by River Reach (See Figure 1) and Habitat Type (Mainstem [M], Backwater [B], or Confluence with Named Tributary).

Habitat	Reach 1		Reach 2	Reach 3		Reach 4		Reach 5	Reach 6		Reach 7	Reach 8		All Whole Body Fish µg/g WW
Element	M	B	M	M	McElmo Creek	M	Mancos River	M	M	B	M	M	B	
Selenium (DW)	3.04	3.08	2.64	2.57	3.30	2.97	3.63	2.20	2.05	3.76	2.89	3.43	2.76	2.60 DW
Aluminum	260	32	208	159	231	183	263	88	100	222	45	25	14	68
Arsenic	0.05	0.11	0.09	0.06	0.08	0.08	0.11	0.07	0.09	0.18	0.06	0.10	0.07	0.08
Barium	4.55	1.96	6.23	3.92	3.75	4.68	3.64	2.39	3.18	4.80	1.89	0.84	2.20	2.49
Beryllium	0.02	0.02	0.01	0.02	0.03	0.02	0.01	0.02	0.02	0.01	0.02	0.00	0.01	0.01
Boron	0.7	0.4	0.3	0.7	0.6	1.6	0.2	0.2	0.5	0.2	0.3	0.2	0.2	0.4
Cadmium	0.03	0.01	0.02	0.03	0.05	0.03	0.02	0.03	0.01	0.04	0.02	0.01	0.01	0.02
Chromium	0.54	0.73	1.06	0.46	1.54	0.27	0.67	0.32	0.24	0.27	0.32	0.11	0.07	0.26
Copper	1.18	0.59	0.81	0.90	1.04	0.93	0.85	0.83	0.89	1.24	1.21	1.40	1.28	1.02
Iron	161	40	153	111	149	122	137	90	95	162	62	33	27	71
Lead	0.16	0.08	0.12	0.17	0.10	0.17	0.11	0.19	0.18	0.40	0.14	0.03	0.05	0.11
Magnesium	333	352	338	336	412	382	347	279	292	342	298	270	292	302
Manganese	5.5	2.8	6.4	5.0	10.3	5.5	6.3	5.0	8.9	25.5	5.7	2.5	2.0	5.0
Mercury	0.033	0.094	0.053	0.068	0.053	0.069	0.026	0.058	0.055	0.018	0.113	0.043	0.043	0.056
Molybdenum	0.30	0.26	0.28	0.28	0.31	0.29	1.00	0.12	0.19	0.09	0.17	0.06	0.10	0.14
Nickel	0.22	0.22	0.51	0.31	0.41	0.26	0.25	0.24	0.24	0.10	0.16	0.06	0.07	0.17
Strontium	23.8	32.4	30.1	26.6	52.5	25.2	36.2	19.7	16.7	22.0	13.9	5.9	15.5	17.5
Vanadium	0.52	0.22	0.60	0.38	0.62	0.33	0.74	0.28	0.35	0.36	0.17	0.07	0.06	0.21
Zinc	27.15	23.89	21.68	25.81	31.01	25.54	28.97	22.77	20.90	29.05	27.62	23.03	31.24	24.32

Table 6. Geometric Mean of Aluminum Concentrations (µg/g, Dry Weight) in Submergent Plants, Invertebrates, and Fish From River Reach 1 Through River Reach 8 of the San Juan River (See Figure 1).

River Reach / Sample Type	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	All Reaches
Submergent Plants	14087		17600	19901	17256	14710	20804	2111	6335
Invertebrates	2440	1778	1589	3001	3968 (8)*	3986 (8)*	2062	637	1502
Whole Body Fish	272 (8)*	800 (7,8)*	606 (7,8)*	687 (7,8)*	307 (8)*	356 (7,8)*	142	80	234
Fish Species									
Bluehead Sucker (BH)			569	1055	496	**CC,FM 1122	786		930
Brown Trout (BT)							22	49	46
Common Carp (CC)	500		396		154	23	88	49	100
Channel Catfish (CF)	453	435	375		171				249
Flannelmouth Sucker (FM)	849	830	628	699	306	**CC 213	157	150	297
Rainbow Trout (RT)							68	84	80
Small Fish (SF)	1398	876	648	757	**CC,CF 1205	**CC 804	439	134	765
Speckled Dace (SD)			644	1138		**CC 451			650

* Samples from this river reach had significantly ($p \leq 0.05$) greater aluminum concentrations than found in samples from the river reach indicated by superscript; identified using dry weight, natural log transformed concentrations without regard to species differences.

** Fish species (identified by species code on left) in this river reach had significantly ($p \leq 0.05$) greater aluminum concentrations than found in other fish species in that reach as indicated by subscript; identified using dry weight, natural log transformed concentrations.

Hazard Assessment

The National Research Council (1980) recommended a protective dietary concentration of 200 µg A/g WW for domestic animals based on reduced growth in fowl fed 500 ug/g aluminum. The geometric mean concentrations of aluminum in all plants and invertebrates collected from the mainstem, as well as whole fish collected from River Reach 1 and River Reach 2 exceeded the 200 µg A/g WW dietary threshold criterion for the protection of avian species. Carriere et al. (1986) observed no adverse effects on avian fertility, hatchability, or fledgling success by doves exposed to 1500 ug Al/g WW. Only plant tissues from the San Juan River mainstem exceeded the Carriere et al. (1986) threshold for effects. If the aluminum found elevated in San Juan River biota were bioavailable, then avian species that eat predominantly plants could begin experience reduced growth and metabolism, especially if their diets were poor in calcium or phosphorus (Schuehammer 1987).

Aluminum burdens in fish exposed to acidic conditions have been implicated in reduced growth and survival for both brook trout (Smith and Haines 1985) and smallmouth bass (Kane and Rabeni 1987). Aluminum toxicity in aquatic plants and invertebrates was enhanced with decreasing pH, phosphate, and calcium (Sparling and Lowe 1996). Sites with low pH and elevated aluminum may result in adverse effects to plants and invertebrates. However, the mean San Juan River pH was often neutral to slightly basic (Abell 1994b). Few studies conducted have explored aluminum toxicity in alkaline conditions.

Table 7. Comparison of San Juan River Aluminum Concentrations (µg/g Wet Weight [WW] or Dry Weight [DW]) in Plants, Invertebrates, and Fish with Ambient Concentrations and Thresholds of Concern.

Data Comparisons and Hazard Assessment

Sample Type	Ambient/Threshold Concentrations	San Juan River Results
Aquatic Plants	Ambient range[a]: 38-6,580 µg/g WW	range: 7 - 10,552 µg/g WW
Invertebrates	Ambient range[a]: 100-4,900 µg/g WW	range: <1 - 1,701 µg/g WW
Whole Body Fish	Ambient range[b]: <3-18,000 µg/g DW	range: <1 - 1,345 µg/g WW
Diet, Birds	Threshold[c]: 200 µg/g WW	plants, invertebrates > threshold
Diet, Doves	No Observed Adverse Effects Level[c]: (NOAEL) 1,500 µg/g WW	plants > NOAEL

Summary of Findings/River Reaches of Concern

Aluminum accumulation in biota seemed to be associated with sediment geochemistry. Biota collected from River Reach 8, a cooler, less turbid stream reach downstream of Navajo Dam contained less aluminum than in biota from downstream, more turbid river reaches. Animals closely associated with sediment, including algae, aquatic worms, and benthic fish species had aluminum concentrations considered regionally elevated. If aluminum concentrations were bioavailable, or if the environment becomes more acidic, and calcium or phosphorus were unavailable, then herbivorous and omnivorous birds might experience adverse effects such as reduced growth and altered metabolism.

[a] Sparling and Lowe 1996; [b] USDOI 1998; [c] National Resources Council 1980

Figure 3. Varimax Normalized Principal Components Analysis (PCA) of San Juan River Plants, Invertebrates, and Whole Fish.

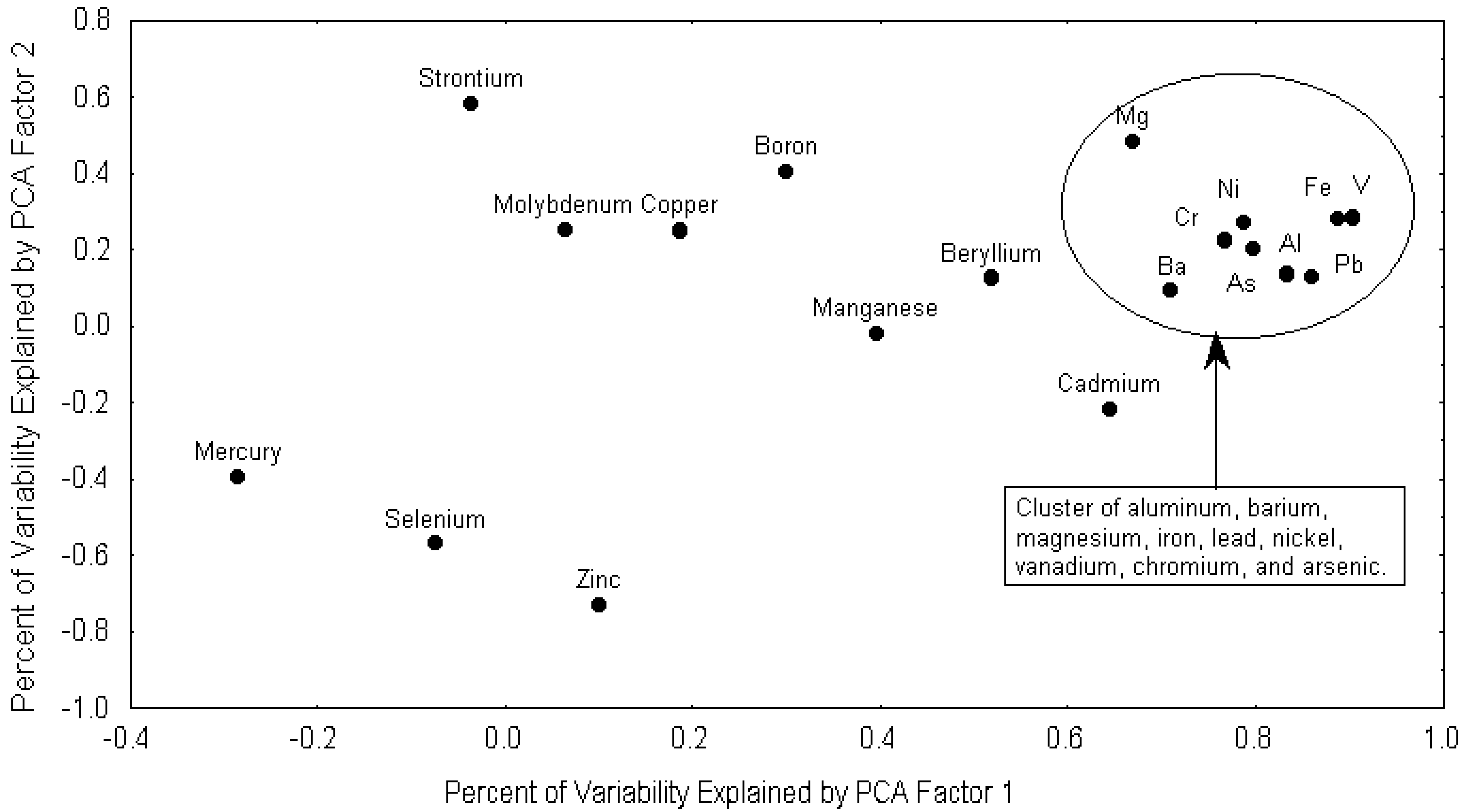


Figure 4. Frequency Plot of Aluminum Concentrations in Aquatic Plants.

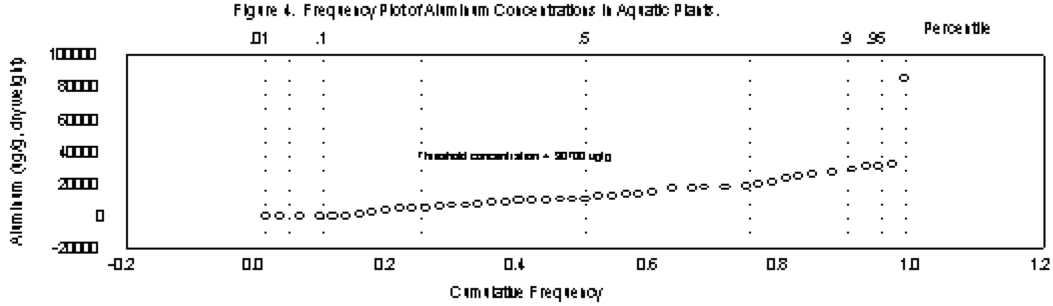


Figure 5. Frequency Plot of Aluminum Concentrations in Invertebrates.

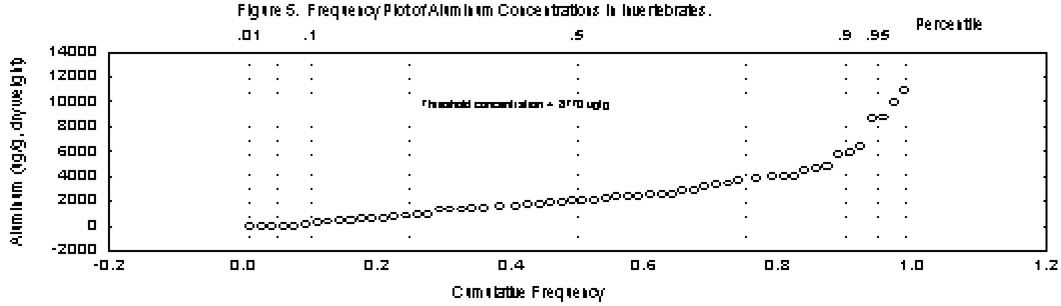
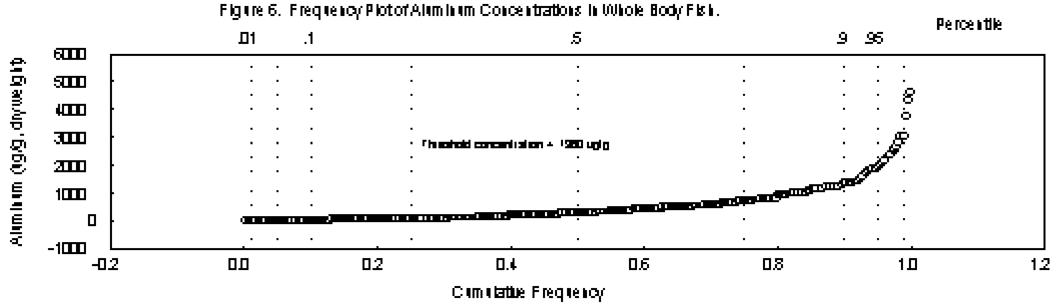


Figure 6. Frequency Plot of Aluminum Concentrations in Whole Body Fish.



Figures 4, 5, & 6. Cumulative Frequency Distribution Plots of Aluminum Concentrations (ug/g, dry weight) in Plants, Invertebrates, and Fish From the San Juan River, 1990-1996.

Arsenic

Data Comparisons

Arsenic concentrations ranged between <0.1 and 12.0 µg/g DW (Appendix A). The highest concentrations were found in periphyton and sediment samples. The number of samples, geometric mean, and range of arsenic concentrations were summarized by river reach, sample type, and fish species in Appendix E. The geometric mean arsenic concentration for submergent plants, invertebrates, and fish species were evaluated by river reach in Table 8. Summary findings regarding arsenic including data comparisons and a hazard assessment are found in Table 9.

Arsenic concentrations in plants with a maximum geometric mean concentration of 5.7 µg/g DW were found in River Reach 7 (Table 8). Arsenic concentrations in aquatic plants from River Reach 1 through River Reach 7 were higher than in aquatic plants from River Reach 8. Arsenic concentrations in plants were below ambient background concentrations (1.4-13 µg/g DW) reported by Eisler (1993).

Geometric mean arsenic concentrations in invertebrates were highest from River Reach 5, but all concentrations were below ambient background concentrations (<1 µg/g WW) reported by Eisler (1993). Arsenic concentrations in whole fish were <0.6 µg/g WW, which were below ambient background concentrations reported by Eisler (1988, 1993). Using the Regional Comparison Method, elevated arsenic concentrations were identified in three periphyton samples (Figure 7), in four invertebrate samples (Figure 8), and in 16 fish samples (Figure 9) that were scattered throughout the San Juan River with no consistent species trends or spatial patterns.

Hazard Assessment

Arsenic concentrations in most aquatic plant samples were considered phytotoxic (>3 mg/kg DW) by Pais and Jones (1997), and above the "Level of Concern" that ranged from 2 to 5 µg/g DW reported by the USDOI (1998). However, these thresholds of concern were derived using higher plants (dicotyledons, gymnosperms, etc.), and may not reflect the potential effects to periphyton and other aquatic plant species collected in the San Juan River. Concentrations of arsenic in invertebrates were below the No Adverse Effects Concentration (30 µg/g DW) reported by the USDOI (1998), although four invertebrates contained arsenic concentrations above the no adverse effects body burden threshold reported by Poulton et al. (1995).

Table 8. Geometric Mean of Arsenic Concentrations (µg/g, Dry Weight) in Submergent Plants, Invertebrates, and Fish from River Reach 1 Through River Reach 8 of the San Juan River (See Figure 1).

Sample Type \ River Reach	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	All Reaches
Submergent Plants	5.17		4.64	3.91	4.76 (8)*	4.22 (8)*	5.71 (8)*	0.96	2.12
Invertebrates	0.49	0.41	0.31	1.05	1.54	1.52	0.84	0.84	0.85
Whole Body Fish	0.30	0.34	0.23	0.29	0.26	0.32	0.20	0.33 (7)*	0.28
Fish Species									
Bluehead Sucker (BH)			0.19	0.46	0.29	**CC,FM 0.56	**FM,RT 0.74		0.48
Brown Trout (BT)							0.15	0.26	0.24
Common Carp (CC)	0.34		0.20		0.26	0.15	0.19	0.19	0.21
Channel Catfish (CF)	0.18	1.00	0.20		0.19				0.21
Flannelmouth Sucker (FM)	0.18	0.18	0.20	0.26	0.21	0.23	0.18	0.14	0.21
Rainbow Trout (RT)							0.09	**CC 0.42	0.31
Small Fish (SF)	0.21	0.25	0.25	0.20	**CF 0.46	0.33	**RT 0.41	0.81	0.31
Speckled Dace (SD)			0.29	0.50		0.33			0.35

* Samples from this river reach had significantly ($p \leq 0.05$) greater arsenic concentrations than found in samples from the river reach indicated by superscript; identified using dry weight, natural log transformed concentrations without regard to species differences.

** Fish species (identified by species code on left) in this river reach had significantly ($p \leq 0.05$) greater arsenic concentrations than found in other fish species in that river reach indicated by subscript; identified using dry weight, natural log transformed concentrations.

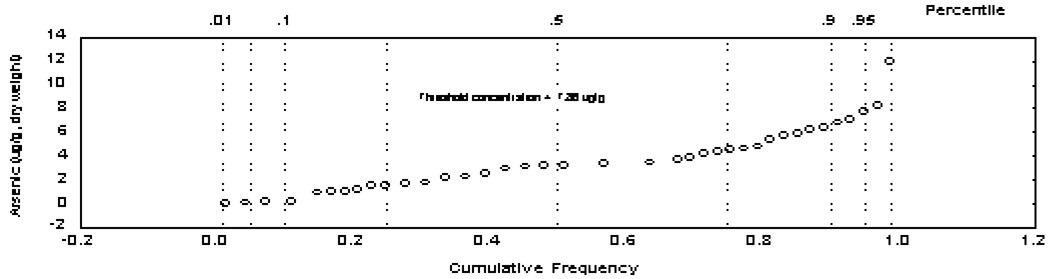


Figure 7. Frequency Plot of Arsenic Concentrations in Aquatic Plants.

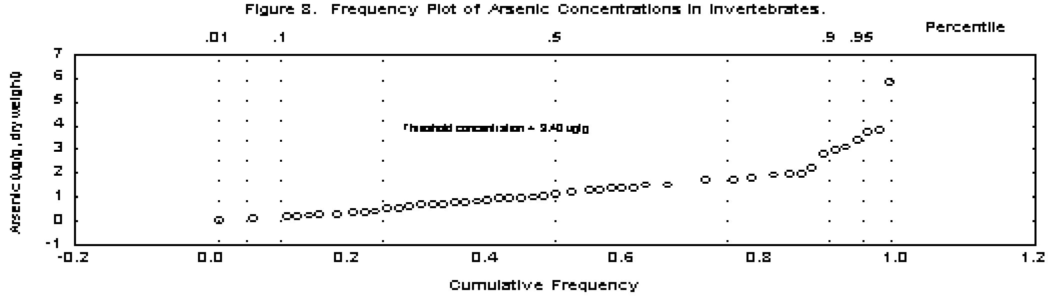


Figure 8. Frequency Plot of Arsenic Concentrations in Invertebrates.

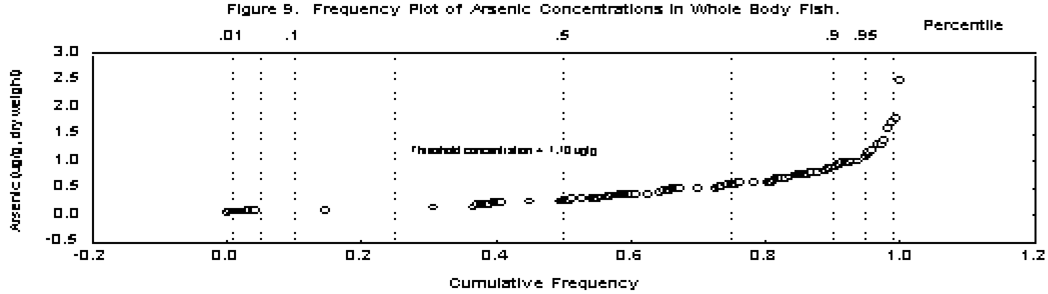


Figure 9. Frequency Plot of Arsenic Concentrations in Whole Body Fish.

Figures 7, 8, and 9. Cumulative Frequency Distribution Plots of Arsenic Concentrations (ug/g, dry weight) in Plants, Invertebrates, and Fish From the San Juan River, 1990-1996.

The majority of whole body fish were below the No Adverse Effects Concentration (<1 µg/g DW) reported by the USDOI (1998). However, 16 fish samples had arsenic concentrations ranging from1.1 to 2.5 µg/g DW, which were within the Level of Concern range (1-12 µg As/g DW) reported by the USDOI (1998). Cockell et al. (1991) found that concentrations less than 10 µg As/g DW had no adverse effects on rainbow trout. Eisler (1994) reported diminished growth and survival in adult fish when arsenic residues in muscle were greater than 5 µg/g WW, which were not found in San Juan River fish muscle. No sample contained arsenic concentrations as high as 30 µg/g WW reported by Camardese et al. (1990) to be associated with reduced growth in duckling diets. Arsenic may pose a risk to plants, to 7% of invertebrates and to 5% of fish analyzed that contained elevated arsenic concentrations. Arsenic toxicity and metabolism varies greatly among species and the toxic effects of arsenic may be altered by numerous modifiers including the chemical form of arsenic in the environment, route of exposure, and the physiological conditions of exposed biota (Eisler 1994).

Table 9. Comparison of San Juan River Arsenic Concentrations (µg/g Dry Weight [DW] or Wet Weight [WW] as indicated) in Plants, Invertebrates, and Fish with Ambient Concentrations and Thresholds of Concern.

Data Comparisons and Hazard Assessment

Sample Type	Ambient/Threshold Concentrations	San Juan River Results
Aquatic Plants	Ambient range[a]: 1.4 - 13 µg/g DW Level of Concern range[b]: 2 - 5 µg/g DW	range:< 0.1 - 12.0 µg/g DW
Invertebrates	Ambient Range[a]: <1 µg/g WW No adverse effects threshold[b]:30 µg/g DW	range: < 0.2 - 0.8 µg/g WW range: < 0.5 - 5.8 µg/g DW
Whole Fish	Level of Concern range[c]: 1 - 12 µg/g DW	range: < 0.5 - 2.5 µg/g DW
Duckling Diet	Reduced growth at >30 µg/g WW	maximum 2.4 µg/g WW

Sites/River Reaches of Concern

Elevated arsenic concentrations were found in most submergent plants and in five percent of the fish analyzed. Arsenic concentrations in plants exceeded concentrations considered phytotoxic to other plant species and some adverse effects to plants. Arsenic was elevated in some invertebrate and whole fish samples. No consistent pattern of arsenic accumulation was identified for any river reach or site. Toxicity of arsenic often depends on its chemical form, route of exposure, and species sensitivity, which were not evaluated in this study. Arsenic concentrations were below the threshold of concern for duckling growth and other avian levels of concern.

[a] Eisler 1994; [b] USDOI 1998; [c] Cockell et al. 1991.

Copper

Data Comparisons

The highest concentrations of copper were found in an invertebrate sample from the mouth of the Mancos River and the lowest copper concentrations were in two walleye samples from the Zahn Bay in Lake Powell. Copper concentrations for each sample analyzed are in Appendix A. The number of samples, geometric mean, and range of copper concentrations are summarized by river reach, sample type, and species in Appendix E. The geometric mean copper concentrations for each sample type and fish species are evaluated by river reach in Table 10. Findings regarding copper including data comparisons and a hazard assessment are summarized in Table 11.

Copper concentrations in aquatic plants ranged between 0.3 and 25 µg/g DW. Using the Regional Comparison Method, four aquatic plant samples were identified as having elevated copper concentrations (Figure 10). Two plant samples were collected near Bluff, Utah, one from Four Corners, New Mexico, and one near Bloomfield, New Mexico. Copper concentrations in aquatic plants from the San Juan River were within ambient background concentrations (2.5-256 µg/g DW) reported by Eisler (1997). Copper concentrations in plants were highly variable and no significant differences were found in plants from different river reaches. However, with the exception of River Reach 1, geometric mean copper concentrations seemed to increase as plants were collected further downstream (Table 10).

Copper concentrations in invertebrates ranged between 4.1 and 150 µg/g DW. Using the Regional Comparison Method, four invertebrate samples were identified as having elevated copper concentrations (Figure 11). One invertebrate sample was collected at the confluence of the Mancos River, one near Clayhills, Utah, one near Bluff, Utah, and one near the confluence of McElmo Creek.

The majority of invertebrates sampled for the Synoptic Study were either not identified to a taxon (e.g., family or genus species) in the field, or were combined without regard to species differences and given the general designation of "macroinvertebrates" by collecting personnel. This made the task of discerning spatial trends or species-specific patterns problematic. Given the lack of species information, it was assumed that the invertebrates collected in the upper river reaches, such as plecopterans (stoneflies), odonates and chironomids (and some earthworms) were coldwater species, while invertebrates collected in the downstream portion of the river, such as trichopterans (midges), and, occasionally, crayfish, were considered warmwater species.

Concentrations of copper in plecopterans from literature reference sites were 16-32 µg/g DW; chironomids, 6 µg/g WW and 11-27 µg/g DW; and earthworms, 3-23 µg/g DW (Eisler 1997; Hattum et al. 1991; Namminga and Wilhm 1977). San Juan River coldwater invertebrates had geometric means of 14.0 µg/g DW from River Reach 7 and 16.3 µg/g DW from River

Reach 8. Eisler (1997) and Hattum et al. (1991) reported ambient background copper concentrations ranging from 11-19 µg/g DW for trichopterans, and 29-160 µg/g DW for crayfish. Warmwater invertebrates collected from the San Juan had whole body residues (4.1 and 150 µg/g DW) within these reported ranges. Copper was highly variable in invertebrates and no significant differences were found in copper concentrations in invertebrates (without regard to taxa) from different river reaches. However, geometric mean copper concentrations seemed to increase as invertebrates were collected downstream (Table 10).

Of whole body fish, copper concentrations were highest in trout samples collected from River Reach 7. Differences in copper accumulations were most evident in River Reach 7, where copper concentrations in rainbow and brown trouts (2.7 - 13.7 µg/g DW) were significantly greater than in either small fish (1.9 - 3.6 µg/g DW) or flannelmouth suckers (1.7 - 4.2 µg/g DW). Without regard to these species differences, whole body fish from River Reach 8 were significantly higher than in fish from lower reaches. This trend was likely the result of different species composition between the reaches. Trouts were only collected in the upper stream reaches and may have influenced the statistical averages for whole body fish. Copper accumulation in trouts in the upstream reaches might be due in part to the insectivorous diet. When trouts were removed from the comparison of whole body copper concentrations in fish, then increasing copper concentrations were found in whole body fish as they were collected downstream; similar to copper trends found in plants and invertebrates.

Using the Regional Comparison Method, 17 fish samples were considered regionally elevated in copper (Figure 12). Twelve of these samples were trouts collected from the upper river reaches, while the other five fish samples containing elevated copper were collected from near Kirtland, New Mexico, Zahn Bay, the Mixer, from a backwater in River Reach 8, and below the confluence of Montezuma Creek.

Source Identification

Source identification of copper in the lower reaches of the river and tributaries may be particularly important due to any toxicological implications of high dietary concentrations of copper to warmwater insectivorous fish such as the razorback sucker. Geometric mean concentrations of copper in invertebrates were elevated in samples collected from the mouth of the Mancos River and McElmo Creek, and also in mainstem sites (Bluff, Clayhills) downstream of these tributaries. High copper loading might be exacerbated by activities within these tributaries.

Considerable mining of copper and other copper-bearing ores have occurred in San Juan County, Utah. According to Bullock (1960), six different copper-bearing minerals from ten different districts have been mined in San Juan County, Utah (Table 11). These sources may contribute to the copper loading found in McElmo and Montezuma creeks, and subsequently to the San Juan River. Between October 1988 and September 1991, 66% of all water samples collected below Montezuma Creek (mean concentration = 19.9 ppb Cu) and 28.6%

of all samples collected below McElmo Creek (mean concentration = 39.7 ppb Cu) exceeded Utah's water quality standards for copper (Utah Division of Water Quality 1992).

Hazard Assessment

Although copper is generally physiologically regulated by biota, high concentrations of copper in the diet could pose health concerns (Eisler 1998). Copper concentrations in plants were within the range (3-30 µg/g DW) reported by the USDOI (1998) to have no adverse effects to the plants themselves. Copper concentrations in San Juan River invertebrates were as high as 41 µg/g WW. Copper concentrations ranging from 17 to 41 µg/g WW fed to rainbow trout have resulted in depressed growth, reduced larval survival, and high copper body burdens (Farag et al. 1994, Farag pers. comm.). Fish consuming invertebrates with elevated copper (> 30 µg/g WW) may have reduced growth (USDOI 1998). Although many trout samples had elevated body burdens of copper (possibly indicating the elevated copper in their invertebrate diets), no trout sample contained whole body copper concentrations that were above the 30 µg/g WW toxicity threshold reported by the USDOI (1998). Additionally, no copper concentrations in biota were above the 200 µg/g DW toxicity threshold in waterfowl diets reported by the USDOI (1998).

Table 10. Geometric Mean of Copper Concentrations (µg/g, Dry Weight) in Submergent Plants, Invertebrates, and Fish Species from River Reach 1 Through River Reach 8 of the San Juan River (See Figure 1).

Sample Type \ River Reach	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	All Reaches
Submergent Plants	15.54		19.64	17.66	16.58	16.84	15.92	8.85	12.39
Invertebrates	49.25	41.02	20.82	35.68	21.80	21.04	13.96	16.26	19.57
Whole Body Fish	2.92	3.11	3.26	3.25	2.92	2.96	3.82	4.94 (1,3,5,6)*	3.52
Fish Species									
Bluehead Sucker (BH)			3.44	3.21	1.87	2.74	3.78		2.79
Brown Trout (BT)							**FM,SF 7.83	4.59	4.74
Common Carp (CC)	3.44		4.30		**CF,BH,FM 5.33	3.77	**FM 4.70	4.21	4.34
Channel Catfish (CF)	3.54	3.13	2.65		1.92				2.40
Flannelmouth Sucker (FM)	4.31	3.22	2.95	3.36	2.57	2.41	2.20	1.94	2.59
Rainbow Trout (RT)							**FM,SF 7.40	**FM 6.15	6.29
Small Fish (SF)	4.43	2.93	2.73	3.07	**CF,BH,FM 4.38	3.16	2.71	2.98	3.28
Speckled Dace (SD)			3.53	3.50		3.88			3.65

* Samples from this river reach had significantly ($p \leq 0.05$) greater copper concentrations than found in samples from the river reach indicated by superscript; identified using dry weight, natural log transformed concentrations without regard to species differences.

** Fish species (identified by species code on left) in that river reach had significantly ($p \leq 0.05$) greater copper concentrations than found in other fish species indicated by subscript in that river reach; identified using dry weight, natural log transformed concentrations.

Figure 10. Plot of Copper Concentrations in Aquatic Plants.

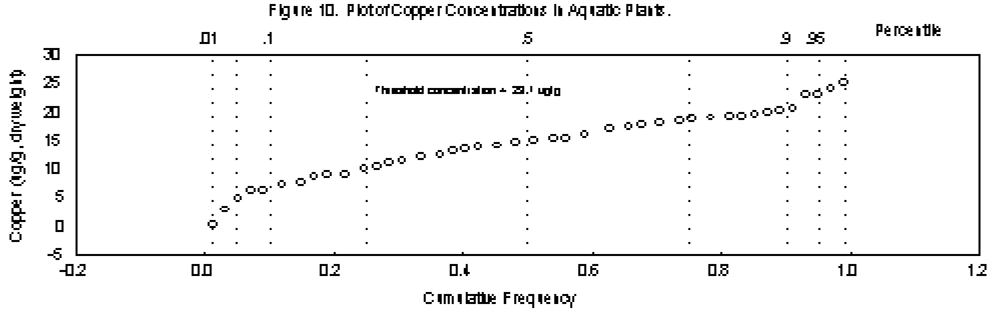


Figure 11. Plot of Copper Concentrations in Invertebrates.

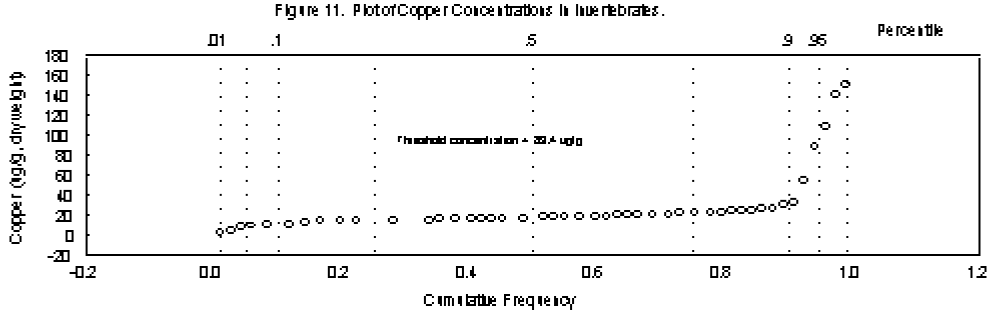
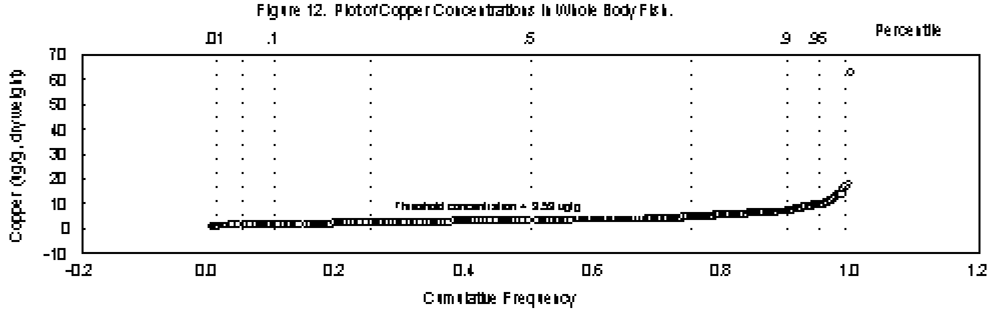


Figure 12. Plot of Copper Concentrations in Whole Body Fish.



Figures 10, 11, and 12. Cumulative Frequency Distribution Plots of Copper Concentrations (ug/g, dry weight) in Plants, Invertebrates, and Fish From the San Juan River, 1990-1996.

Table 11. Mineral Names, Chemical Formula, and Areas Mined in San Juan County, Utah.

Mineral	Chemical Formula[a]	Areas Mined	Notes
Azurite	$Cu_3(CO_3)_2(OH)_2$	Monument Valley District	Highly associated with copper deposits
Carnotite	$K_2(UO_2)_2(VO_4)_2 \bullet H_2O$	Browns Hole Area, Cane Springs Pass, Montezuma Canyon, Monticello District, Monument Valley District, Navajo Reservation, Paradox District, Red Canyon	Highly associated with copper deposits
Chalcocite	Cu_2S	Red Canyon	
Chalcopyrite	$CuFeS_2$	San Juan River near Bluff	
Malachite	$Cu_2(CO_3)(OH)_2$	Monument Valley District, Red Canyon	Highly associated with copper deposits
Torbenite	$Cu(UO_2)_2(PO_4)_2 \bullet 8\text{-}12\ H_2O$	Monument Valley District, Paradox District	
Tyuyamunite	$Cu(UO_2)_2(VO_4)_2 \bullet 5\text{-}8\ H_2O$	Monticello District	

[a] Formula and information derived from American Geological Institute, 1984.

Table 12. Comparison of San Juan River Copper Concentrations (µg/g Dry Weight [DW] or Wet Weight [WW] as indicated) in Plants, Invertebrates, and Fish with Ambient Concentrations and Thresholds of Concern.

Data Comparisons and Hazard Assessment

Sample Type	Ambient/Threshold Concentrations	San Juan River Results
Aquatic Plants	Ambient Range[a]: 2.5-256 µg/g DW No Adverse Effects Range[b]:3-30 µg/g DW	Range: 0.3 and 25 µg/g DW
Invertebrates	Coldwater Invertebrates[a,c,d] Plecopterans: 16-32 µg/g DW Warmwater Invertebrates[a,b] Trichopterans: 11-19 µg/g DW Crayfish: 29-160 µg/g DW	Upper River Reach range: 4.1 to 55.7 µg/g DW Lower River Reach range: 9.5 to 150 µg/g DW
Whole Fish	Toxic Effects Threshold[b]: 30 µg/g WW	maximum 20.4 µg/g WW
Fish Diet	Adverse effects[d]: 17-41 µg/g WW	plant maximum: 8.4 µg/g WW (25 µg/g DW)
Bird Diet	Adverse effects[b]: 200 µg/g DW	invertebrate maximum: 40.5 µg/g WW (150 µg/g DW) fish maximum: 20.4 µg/g WW (63 µg/g DW)

Sites/River Reaches of Concern

Elevated copper in invertebrates may have augmented body burdens of copper in insectivorous trouts collected from the upstream coldwater river reaches. With trouts removed, plants, invertebrates, and whole fish all show increased copper concentrations as they were collected downstream. As copper concentrations increased in invertebrates in the lower river reaches, insectivorous fish species, perhaps including the resident razorback sucker, would also be exposed to elevated copper in their diet potentially resulting in elevated body burdens or reduced growth and larval survival. Copper was not likely to pose a health risk to waterfowl.

[a] Eisler 1997; [b] USDOI 1998; [c] Hattum et al. 1991; [d] Farag et al. 1994.

Mercury

Data Comparisons

The highest concentrations of mercury were found in a striped bass sample collected from the San Juan arm of Lake Powell near Piute Farms, Utah. Mercury concentrations for each sample analyzed are reported in Appendix A. The number of samples, geometric mean, and range of mercury concentrations are summarized by river reach, sample type, and species in Appendix E. The geometric mean mercury concentration for each sample type and fish species are evaluated by river reach in Table 13. Findings regarding mercury including data comparisons and a hazard assessment are summarized in Table 14.

Mercury concentrations in aquatic plants ranged from <0.1 to 0.11 µg/g DW (<0.035 to 0.020 µg/g WW). Using the Regional Comparison Method, three aquatic plant samples were identified as having elevated mercury concentrations (Figure 13). These plant samples were all collected in New Mexico (at Four Corners, Farmington, and Bloomfield). Concentrations of mercury in plants from River Reach 3 through River Reach 7 had significantly higher concentrations of mercury in aquatic plants than River Reach 8 (Table 13). The mercury concentrations in San Juan aquatic plants were below or equal to those reported as ambient background by Eisler (1987).

Mercury concentrations in invertebrates ranged from <0.1 to 0.2 µg/g DW (<0.025 to 0.07 µg/g WW). Using the Regional Comparison Method, three invertebrate samples were identified as having elevated mercury concentrations (Figure 14). All three samples were collected in the upstream river reaches. However, concentrations in invertebrates were not significantly different between reaches. Mercury concentrations in invertebrates from the San Juan River were below those of insects (0.21 µg Hg/g WW), stoneflies (0.07 µg Hg/g WW), and crustaceans (0.06-0.56 µg Hg/g WW) reported from uncontaminated areas (Huckabee et al. 1979, Jenkins 1980).

Of whole body fish in the San Juan River mainstem, the highest geometric mean mercury concentration was found in whole fish from River Reach 7. Significant differences in mercury accumulation was noted in brown trout, common carp, small fish, and flannelmouth sucker compared to these fish in other reaches (Table 13). Without regard to these species differences, whole body fish from River Reach 7 were significantly higher than in fish from River Reach 5, River Reach 6, and River Reach 8.

Using Regional Comparison Method, 16 fish samples were considered regionally elevated for mercury (Figure 15). Of these, fish species varied; nine were flannelmouth suckers, three were common carp, two were catfish, and one was a walleye and one a striped bass. Nine samples were collected from the upstream river reaches (River Reach 6 through River Reach 8) and three samples were collected from River Reach 1. No seasonal variation or correlation with length or weight or feeding guild was found. Stafford and Haines (1997), Richens and

Risser (1975), and Walter et al. (1973) reported ambient concentrations of mercury at uncontaminated sites for trouts (0.1-0.4 µg/g WW), common carp (0.07-0.5 µg/g WW), sucker species (0.02-0.33 µg/g WW), and channel catfish (0.1-0.3 µg/g WW). Concentrations of mercury in whole body fish from the San Juan River (<0.05 - 0.32 µg/g WW) were within the range of these concentrations. Analysis of whole body fish from reservoirs and rivers in Montezuma, La Plata, and Dolores counties in southwestern Colorado led investigators to conclude that mercury residues in fish were the result of sedimentary mercury-bearing rock (Standiford et al. 1973, Abell 1994a). Mercury burdens in the San Juan River fish may reflect geologic sources but also ambient mercury pollution in the environment and atmospheric deposition (USEPA 1997).

Hazard Assessment

Twenty-eight percent (56/202) warmwater fish species samples were above the no effects threshold (0.11 µg/g WW) for bluegill reported by the USDOI (1998). No fish exceeded the 0.5 µg/g WW maximum criterion for aquatic organisms (Environment Ontario 1984) or 1 µg/g WW toxicity threshold (USDOI 1998). All invertebrates contained mercury below the dietary threshold of toxicity to mallards (USDOI 1998). Only three samples (all large fish) contained mercury concentrations above the dietary toxicity threshold for loons (USDOI 1998). Eisler (1987) recommended that for the protection of sensitive species of birds that regularly consume fish, that total mercury concentrations in the fish should not exceed 0.1 µg/g WW. Twenty-two percent of fish samples (70/313) exceeded the 0.1 µg/g WW protective recommendation.

Table 13. Geometric Mean of Mercury Concentrations (µg/g, Dry Weight) in Submergent Plants, Invertebrates, and Fish from River Reach 1 Through River Reach 8 of the San Juan River (See Figure 1).

River Reach / Sample Type	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	All Reaches
Submergent Plants	0.03		$0.05^{(8)*}$	$0.07^{(8)*}$	$0.05^{(8)*}$	$0.04^{(8)*}$	$0.05^{(8)*}$	0.02	0.03
Invertebrates	0.07	0.07	0.07	0.03	0.04	0.06	0.09	0.06	0.06
Whole Body Fish	0.24	0.20	$0.23^{(6)*}$	0.21	0.20	0.15	$0.36^{(5,6,8)*}$	0.16	0.20
Fish Species									
Bluehead Sucker (BH)			0.27	0.16	0.10	0.10	0.19		0.12
Brown Trout (BT)							0.43	0.14	0.14
Common Carp (CC)	0.22		0.26		$_{**BH}0.24$	0.24	$_{**BH,RT}0.45$	$_{**BT,RT}0.24$	0.27
Channel Catfish (CF)	0.29	0.23	0.35		$_{**BH}0.27$				0.28
Flannelmouth Sucker (FM)	0.19	0.17	0.22	0.27	$_{**BH}0.22$	$_{**BH}0.22$	$_{**BH,RT}0.51$	$_{**BH,BT,RT,SF}0.60$	0.26
Rainbow Trout (RT)							0.22	0.13	0.15
Small Fish (SF)	0.11	0.21	0.18	0.12	0.15	0.14	0.35	0.09	0.17
Speckled Dace (SD)			0.33	0.29		$_{**BT}0.37$			0.33

* Samples from this river reach had significantly ($p \leq 0.05$) greater mercury concentrations than found in samples from the river reach indicated by superscript; identified using Dry Weight, natural log transformed concentrations without regard to species differences.

** Fish species (identified by species code on left) in that river reach had significantly ($p \leq 0.05$) greater mercury concentrations than found in other fish species indicated by subscript in that river reach; identified using dry weight, natural log transformed concentrations.

Figure 13. Plot of Mercury Concentrations in Aquatic Plants.

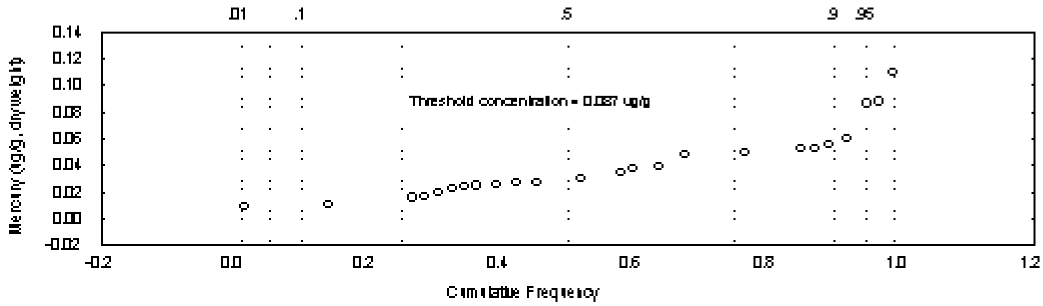


Figure 14. Plot of Mercury Concentrations in Invertebrates.

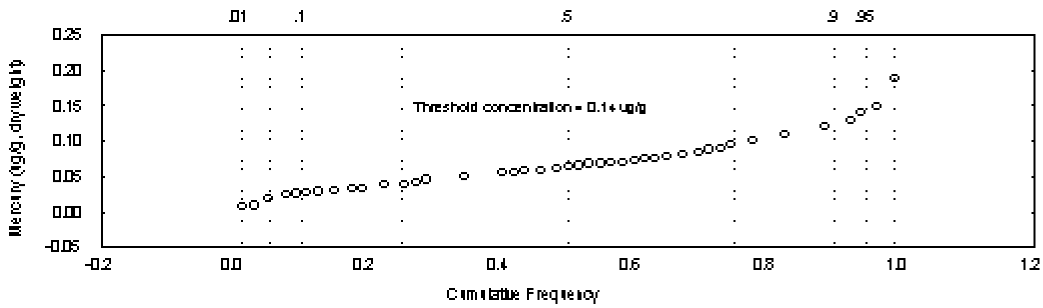
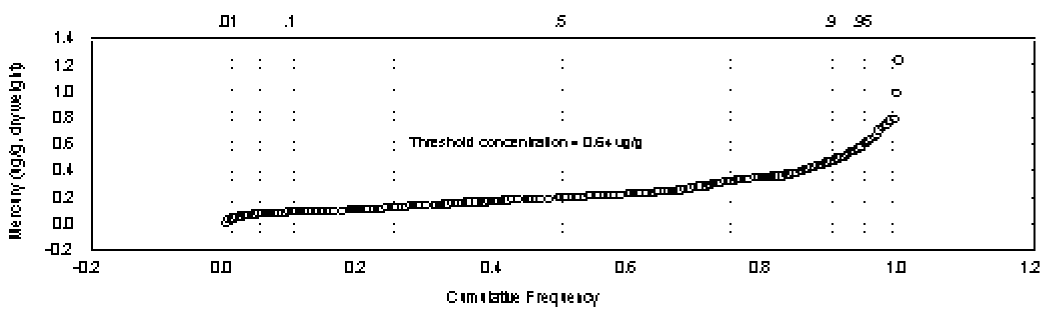


Figure 15. Plot of Mercury Concentrations in Whole Body Fish.



Figures 13, 14, and 15. Cumulative Frequency Distribution Plots of Mercury Concentrations (ug/g, dry weight) in Plants, Invertebrates, and Fish From the San Juan River, 1990-1996.

Table 14. Comparison of San Juan River Mercury Concentrations (µg/g Wet Weight [WW] or Dry Weight [DW] as indicated) in Plants, Invertebrates, and Fish with Ambient Conditions and Thresholds of Concern.

Data Comparisons and Hazard Assessment

Sample Type	**Ambient/Threshold Concentrations**	**San Juan River Results**
Aquatic Plants	Ambient mean[a]: 0.02 µg/g WW	maximum geometric mean: 0.02 µg/g WW
Invertebrates	Ambient invertebrates[b,c]:0.05-0.56 µg/g WW	<0.025 to 0.07 µg/g WW
Whole Fish	Ambient ranges:	
	Brown trout[d]: 0.12-0.45 µg/g WW	trout:<0.01-0.16 µg/gWW
	Common carp[e]: 0.069-0.503 µg/g WW	carp: 0.02-0.65 µg/g WW
	Suckers[e]: 0.020-0.333 µg/g WW	sucker:0.02-0.09µg/g WW
	Channel catfish[f]: 0.13-0.29 µg/g WW	catfish:0.30-0.2 µg/g WW
	Concern in whole body fish[g,h,]:0.5 µg/g WW	1 carp sample>0.5 µg/g WW
Bird Diet	Protection of sensitive birds[g]: 0.1 µg/g WW	22% fish > 0.1µg/g WW

Sites/River Reaches of Concern

Plants, invertebrates and most fish were below thesholds of concern for mercury or within the ambient ranges reported from other reference areas. Twenty-two samples of fish (mostly from upstream reaches) exceeded the protective concentration in the diets of sensitive species of birds. Piscivorus birds that feed in upstream reaches could be at risk for mercury toxicity.

[a] Eisler 1987; [b] Huckabee et al. 1979; [c] Jenkins 1980; [d] Stafford and Haines 1997; [e] Richens and Risser, Jr. 1975,[f] Walter et al. 1973; [g] USDOI 1998; [h] Environment Ontario 1984.

Selenium

Data Comparisons

The highest concentrations of selenium in biota collected from the San Juan River mainstem (18 µg/g DW) were found in invertebrate samples collected from River Reach 8, below Navajo Dam. The highest inventoried concentrations of selenium in plants (20 µg/g DW\), invertebrates (32.5 µg/g DW), amphibians (52 µg/g DW), and whole fish (41.7 µg/g DW) collected in the San Juan River Basin, including off-channel habitats (e.g., irrigation drains, ponds), were reported by Blanchard et al. (1990) and Thomas et al. (1997). Selenium concentrations for each sample analyzed in the Synoptic Study are reported in Appendix A. The number of samples, geometric mean, and range of selenium concentrations are summarized by river reach, sample type, and species in Appendix E. The geometric mean selenium concentrations for each sample type and fish species are evaluated by river reach in Table 15. Selenium concentrations in endangered fish tissues are reported in Table 16. Findings regarding selenium including data comparisons and a hazard assessment are summarized in Table 17.

Selenium concentrations in aquatic plants ranged from <0.2 to 4.4 µg/g DW. Selenium concentrations in aquatic plants (≈ 1 µg/g DW) were not significantly different by river reach designation (Table 15). Using the Regional Comparison Method, five aquatic plant samples were identified as having elevated selenium concentrations (Figure 16), and were collected from upstream of the confluence of San Juan's confluence with the Animas River. Saiki (1985, 1987), Maier and Knight (1994), and the USDOI (1998) reported background selenium concentrations in aquatic plants of less than 1.5 µg/g DW. Twenty-one per cent (12/58) of all plant samples from the San Juan River mainstem were above the 1.5 µg/g DW background concentration; over half these samples (7/12) were collected from River Reach 8.

Selenium concentrations in aquatic invertebrates ranged from <0.4 to 18.0 µg/g DW. Selenium concentrations in invertebrate samples (≈ 3.3 µg/g DW) were not significantly different by river reach designation (Table 15). Using the Regional Comparison Method, four invertebrate samples were identified as having regionally elevated selenium concentrations (Figure 16). Three of these invertebrates were collected from River Reach 8 and one sample was collected from the Navajo Reservoir.

Maier and Knight (1994) reported a range of background selenium concentrations from 0.5 to 2.0 µg/g DW in invertebrates. Eighty-one per cent (70/86) of invertebrates collected from the San Juan River were above the Maier and Knight (1994) upper background concentration. The USDOI (1998) reported background selenium concentrations in invertebrates ranging from 0.4 to 4.5 µg/g DW. Thirty-four per cent (29/86) of invertebrates collected from the San Juan River were above the USDOI (1998) upper background concentration. Of these, 25 samples were collected from River Reach 7 and River Reach 8, while three samples were collected from River Reach 6 and one sample was collected from the Mancos River confluence.

Selenium concentrations varied widely in: trouts (0.6-15.1 µg/g DW); dace (2.1-11.0 µg/g DW); catfish (1.2-10.3 µg/g DW); carp (1.3-6.8 µg/g DW); suckers (0.1-5.4 µg/g DW); and the remaining "small fish" samples (0.2-14.3 µg/g DW). Without regard to the site of fish collection, significant differences were found between the selenium concentrations of each fish species (Table 15) or group (i.e., trouts included rainbow and brown trout, "small fish" included different species). Selenium concentrations in dace were significantly higher than those in all other fish species (Figure 19). Selenium concentrations in trouts were significantly higher than those in catfish, carp, or sucker species. Selenium concentrations were significantly lower in sucker species than found in trouts, dace, and other small fish samples. Schematically, selenium accumulation in fish was generally: Patterns of Selenium Accumulation in San Juan River Fish dace> small fish, trouts> common carp > catfish, bluehead sucker, flannelmouth sucker.

Species selection is critical in the long-term monitoring and interpretation of selenium contamination. Selection of sucker species for monitoring selenium contamination of the San Juan River fishery could result in an underestimation of potential risk. The ability to detect long term trends would also be difficult using a species with a narrow and low range of selenium accumulation. Species composition by river reach affected the ability to determine site-specific trends. Without regard to species, selenium concentrations were significantly higher in fish collected from River Reach 7 and River Reach 8 compared to those in fish from River Reach 6 (Table 15). This could be attributable to the abundance of small fish, dace, and trouts in the upstream collections compared with collections downstream. Selenium concentrations in flannelmouth suckers, bluehead suckers, and small fish, however, were not significantly different by river reach.

Thirty-one whole body fish samples were considered regionally elevated (using the RCM). Species of fish previously identified (small fish, dace, and trouts) comprised the majority of fish species that were considered regionally elevated; eleven were small fish, eight were dace species, seven were rainbow trout, and four were brown trout. (The remaining sample was composed of channel catfish collected near Mexican Hat, Utah). Most regionally elevated samples were collected from the upper reaches of the river, although small fish and dace were also collected from most river reaches, particularly at the mouths of tributaries.

Seasonal variations in selenium concentrations were evident in carp, the only fish species sampled sufficiently during different seasons. Common carp had significantly lower selenium concentrations when collected in the summer than those in carp collected in the spring, fall, or winter (Figure 20). This trend could be attributable to seasonal habitat preferences, the productivity of the habitat, irrigation return, growth rates, spawning condition, or other dietary preferences of common carp in the summer compared with other seasons. Zooplankton and fresh algal growth might become more abundant in the summer and be a preferred diet item by carp. In the spring, fall, and winter, carp may feed more on detritus and such dietary changes, in addition to other physiological variables, which could be reflected in selenium body burdens.

Selenium concentrations in whole body fish collected from the San Juan River ranged from 0.1 to 15.1 µg/g DW. Concentrations in whole body razorback sucker introduced and later collected from the San Juan River ranged from 3.8 to 4.3 µg Se/g DW. Concentrations in whole body fish from uncontaminated conditions are often below 2 µg Se/g DW (Hodson et al.1980, Hilton et al.1980, Hodson and Hilton 1983, Schultz and Hermanutz 1990, Cleveland et al.1993, Hamilton et al.1998, USDOI 1998) and were 1.2 µg/g DW in razorback sucker from uncontaminated laboratory conditions (Hamilton et al. 2000).

Four hundred and seven whole body fish (67%) and the razorback suckers collected from the San Juan River exceed the 2 µg/g DW background concentration. The 85th percentile values (2.5 µg/g DW) for fish sampled nationwide also exceeded the 2 µg/g DW background concentration and those samples were often sampled from the Colorado River Basin. Clearly, the majority of fish from the San Juan River contain elevated selenium concentrations.

Razorback Sucker/Colorado Pikeminnow Tissues

The results of selenium analyses on endangered fish tissues collected from River Reach 2 to River Reach 6 are provided in Table 2. Of the data available, no spatial trends were found using razorback sucker or the Colorado pikeminnow muscle plug selenium concentrations. Selenium concentrations in razorback sucker muscle plugs collected prior to the introduction of these fish to the San Juan River in 1994 ranged from 2.9 to 4.8 µg/g DW (Table 2). Selenium concentrations ranged from 1.1 to 11 µg/g DW in razorback sucker muscle plugs collected after recapture of cohorts in 1995. However, there were no statistically significant differences in the accumulation of selenium concentrations in muscle plugs of cohort razorback suckers before and after exposure to the San Juan River environment. The geometric mean selenium concentration in razorback muscle tissue was 3.23 µg/g DW prior to San Juan River introduction and was 3.94 µg/g DW after their introduction.

Given the variability of selenium accumulation in muscle plugs (standard deviation =1.6 µg/g DW) and the number of samples available for analyses before (n=5) and after San Juan River exposure (n= 25), only a 2 µg/g DW difference in mean selenium concentrations could have been detected as significant. Nearly 500 samples would be necessary to determine if a 0.7 µg/g DW difference in mean selenium concentrations found before and after introduction into the San Juan River would have been significantly different.

Table 15. Geometric Mean of Selenium Concentrations (µg/g, Dry Weight) in Submergent Plants, Invertebrates, and Fish from River Reach 1 Through River Reach 8 of the San Juan River (See Figure 1).

Sample Type \ River Reach	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	All Reaches
Submergent Plants	0.92		0.86	1.04	0.70	0.78	0.58	1.06	0.86
Invertebrates	2.87	3.02	2.48	3.40	2.47	3.44	3.88	3.35	3.26
Whole Body Fish	3.06	2.64	2.71	3.05	2.20	2.13	2.81 (5,6)*	3.27 (6)*	2.60
Fish Species									
Bluehead Sucker (BH)			2.09	1.87	1.66	1.51	2.15		1.82
Brown Trout (BT)							$^{**}_{BH,CC,FM,RT}$ 6.71	$^{**}_{CC,FM}$ 4.58	4.88
Common Carp (CC)	2.68		3.93		$^{**}_{BH,CF,FM}$ 3.85	$^{**}_{BH}$ 2.54	$^{**}_{BH,FM}$ 3.46	2.06	2.95
Channel Catfish (CF)	2.28	4.65	2.27		2.06				2.25
Flannelmouth Sucker (FM)	2.87	0.78	1.84	2.57	1.96	$^{**}_{BH}$ 1.84	2.58	2.04	2.12
Rainbow Trout (RT)							$^{**}_{BH,CC,FM}$ 4.75	$^{**}_{CC,FM}$ 3.40	3.62
Small Fish (SF)	3.37	5.67	3.27	4.72	$^{**}_{BH,CF,FM}$ 4.26	$^{**}_{BH,CC,CF,FM}$ 4.46	$^{**}_{BH,CC,FM,RT}$ 6.12	4.02	4.43
Speckled Dace (SD)			6.30	$^{**}_{FM}$ 6.75		5.76 $^{**}_{BH,BT,CC,CF,FM,RT}$	6.62 $^{**}_{BH,CC,FM,RT}$		6.14

- Samples from this river reach had significantly ($p \leq 0.05$) greater selenium concentrations than found in samples from the river reach indicated by superscript; identified using dry weight, natural log transformed concentrations without regard to species differences.

** Fish species (identified by species code on left) in that river reach had significantly ($p \leq 0.05$) greater selenium concentrations than found in other fish species indicated by subscript in that river reach; identified using dry weight, natural log transformed concentrations.

Figure 16. Plot of Selenium Concentrations in Aquatic Plants.

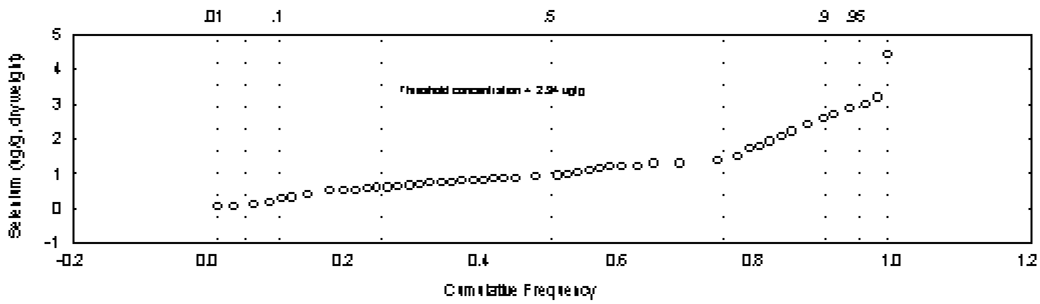


Figure 17. Plot of Selenium Concentrations in Invertebrates.

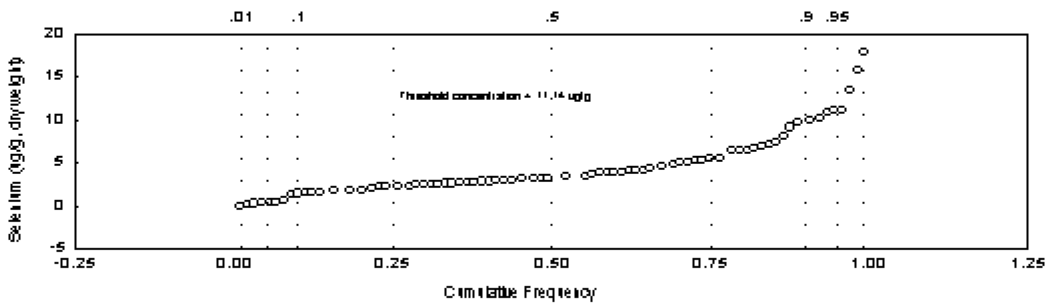
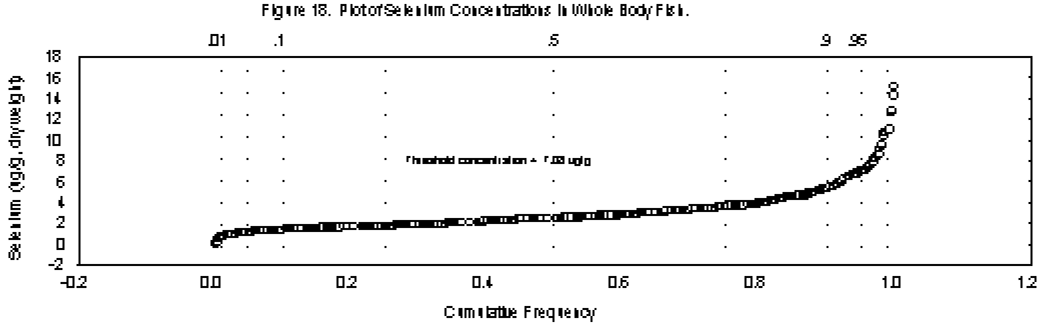


Figure 18. Plot of Selenium Concentrations in Whole Body Fish.



Figures 16, 17, and 18. Cumulative Frequency Distribution Plots of Selenium Concentrations (ug/g, dry weight) in Plants, Invertebrates, and Fish From the San Juan River, 1990-1996.

Figure 19. Box Plots of Selenium Concentrations in Fish Grouped by Category, San Juan River, 1990-1996.

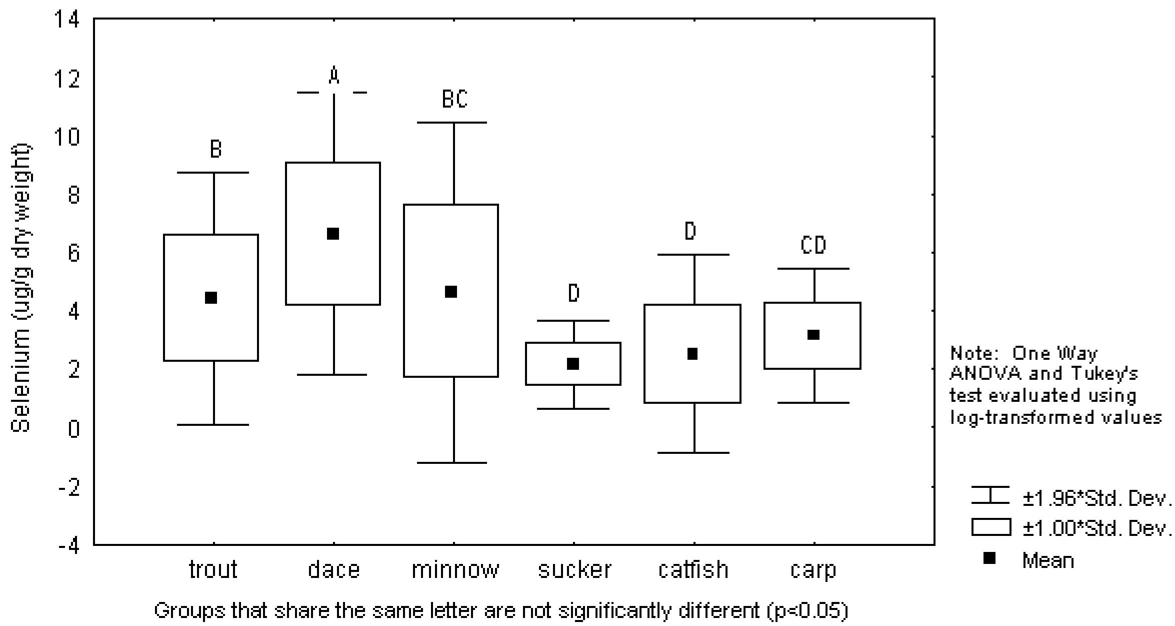
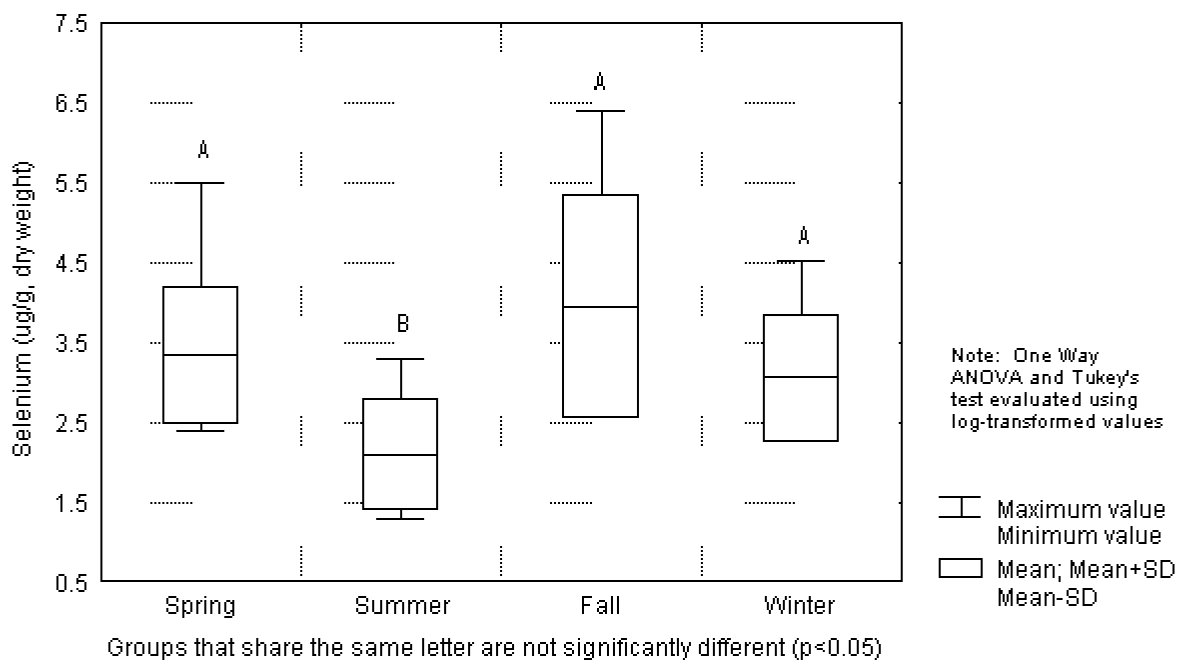


Figure 20. Selenium Concentrations in Common Carp by Season



Lemly (1993, 1996) reported that the most precise way to assess selenium risks to fish is to measure selenium in gravid ovaries. Selenium concentrations were not measured in ovaries from the species of interest, razorback sucker and Colorado pikeminnow, but they were measured in flannelmouth sucker ovaries from River Reach 6 and ranged from 3.5 to 5.5 µg/g DW. For flannelmouth sucker, the geometric mean selenium concentration in ovaries was four times higher than in muscle tissues (Table 16). If selenium concentrations were 2 to 5 times higher in egg tissues than in muscle concentrations for the Colorado pikeminnow, as suggested by Buhl and Hamilton (1998), then egg/larvae concentrations in Colorado pikeminnow would range from 6.5 to 16.3 µg/g. However, the selenium concentrations in ovaries of razorback sucker of the Green River reported by Hamilton and Waddell (1994) were 57% less than those in muscle tissues (Table 16). If this 57% factor was applied to San Juan River razorback sucker muscle plug selenium concentrations, then the geometric mean selenium concentration in their ovaries would be expected to be 2.2 µg/g DW (Table 16). If selenium concentrations in flannelmouth sucker eggs and muscle tissue in the San Juan River were assumed to parallel the selenium concentrations in razorback sucker eggs and muscle tissues, then the geometric mean selenium concentration would be expected to be 16.3 µg/g DW (Table 16). If selenium concentrations in flannelmouth sucker eggs and their whole body in the San Juan River were assumed to parallel the selenium concentrations in razorback sucker ovaries and their whole body, then the geometric mean selenium concentration in razorback sucker ovaries was expected to be 7.4 µg/g DW (Table 2).

Table 16. Whole Body, Muscle, and Egg Selenium Concentrations (µg/g DW) in Razorback Sucker, Colorado Pikeminnow, and Flannelmouth Suckers Collected from the Green River and the San Juan River.

SPECIES (COMMON NAME)	WHOLE BODY		MUSCLE		EGGS	
	N[a]	GMEAN[b]	N	GMEAN	N	GMEAN
SAN JUAN RIVER, UTAH AND NEW MEXICO						
Razorback Suckers collected from River Reach 2 through River Reach 6	3	3.97	25	3.94		[2.2 / 7.4 / 16.4][c]
Flannelmouth suckers from Reach 6	11	2.50	6	1.11	15	4.63
Colorado pikeminnows collected from River Reach 3 and River Reach 4			4	3.23		
GREEN RIVER, UTAH						
Razorback suckers from "Razorback Bar"		[10.1][c]	3	9.99[d]	3	5.69[d]

[a] N = number of samples
[b] GMEAN = geometric mean concentration, µg/g Dry Weight
[c] values in brackets were estimated using egg-to-muscle or muscle-to-whole body ratios (see text)
[d] Hamilton and Waddell 1994, Waddell and May 1995

Source Identification

Sources of selenium, both anthropogenic and natural, in the San Juan River, have been reported by O'Brien (1987), Blanchard et al. (1993), and Thomas et al. (1998). Thomas et al. (1998) evaluated five factors affecting selenium dynamics in the San Juan River, including bioaccumulation, soil-leaching, evapoconcentration, atmospheric deposition, and point-source contamination. Thomas et al. (1998) concluded that the variability of selenium in water, sediment, and biota was attributable to the underlying geology of the sites studied. Plants, invertebrates, and fish that were collected from sites receiving seepage or leachate from Cretaceous-Age soils had accumulated significantly higher concentrations of selenium than did samples which were underlain by non-Cretaceous-Age soils. Keller-Bliesner Engineering (1991, 1999) also reported that the leaching of Cretaceous-Age soils contributed selenium-rich groundwater to the San Juan River.

The San Juan River is a dynamic system and the underlying alluvial substrate was deposited recently, in the Quaternary Era, while portions of the surrounding uplands were deposited during the Cretaceous Era and are selenium-rich (Thomas et al. 1998). Snowmelt from tributaries originating in southwestern Colorado comprised the majority of source water for the San Juan River and given its steep slope (Holden 1999), this snowmelt provides an abundant dilution capacity for selenium-rich tributary waters downstream. Selenium concentrations in river water were generally low (<1 µg/L) within the mainstem of the San Juan River (Thomas et al. 1998). Aquatic systems where water concentrations are <1 µg/L were generally considered to pose little risks to aquatic fish and wildlife (Peterson and Nebeker 1992). However, ponds, seeps, tributaries and irrigation drains in the downstream river reaches contain selenium concentrations in water from <1 to 12 µg/L with concordant increased selenium burdens in the resident biota from these habitats, although underlying soil was the primary factor for the relative differences (Thomas et al. 1998). Fish or wildlife that utilize resident mainstem prey *exclusively* would likely have reduced selenium exposure compared to those animals that utilize the off-channel habitats extensively (e.g., backwaters, tributary mouths, irrigation drains, and ponds on Cretaceous Age soils), where elevated selenium accumulation was prevalent. Therefore, fish utilizing these habitats would have increased selenium exposure, body burdens, and potentially increased incidence of selenium-associated health risks.

Hazard Assessment

The USDOI (1998) reported that growth was reduced in algae with concentrations as high as 4.0 µg/g DW. One plant sample collected below the Navajo Dam in River Reach 7 (River Mile 196) contained a selenium concentration (4.4 µg/g DW) above this sublethal threshold. The USDOI (1998) reported that sublethal effects to invertebrates with whole body selenium concentrations ranged from 2.5 to 15 µg/g DW. Thirty-nine invertebrate samples exceeded the lower potential toxic effects range (2.5 µg/g DW), while only one invertebrate sample exceeded the upper potential toxic effects range (15 µg/g DW). Allert et al. (1999), however, reported that invertebrate composition and density varied by river reach, but attributed substrate as the primary factor affecting the integrity of the invertebrate community.

Selenium concentrations in whole body fish above 4 µg/g DW have been associated with adverse effects such as mortality, reduced growth, and reproductive failure (Hilton et al. 1980, Hodson and Hilton 1983, Ogle and Knight 1989, Cleveland et al. 1993, Lemly 1996, Hamilton et al. 1998, USDOI 1998). One hundred and eighteen fish samples (19%) collected from the San Juan River mainstem exceeded the 4 µg/g DW toxicity threshold. Seventy-six percent of these fish were collected between River Reach 6 upstream to River Reach 8; 40% were trouts and 41% were small fish or dace. One razorback sucker (of three sampled) was above this threshold.

Selenium concentrations ranging from 7 to 13 µg/g DW in egg tissues of sensitive species of fish may result in hatching/reproductive failure (USDOI 1998). Selenium concentrations greater than 13 µg/g DW in egg tissues could result in larval deformities (teratogenesis) in sensitive fish species (USDOI 1998). Selenium concentrations in flannelmouth sucker ovaries collected from River Reach 6 did not exceed either the reproductive impairment or teratogenesis thresholds. Using a number of assumptions (emphasizing the need for empirical data), if the geometric mean selenium concentration in razorback sucker egg tissues was 2.2 µg/g DW, then there would likely be no reproductive failure; 7.4 µg/g DW, then there would be some likelihood of reproductive failure; and 16.3 µg/g DW would likely result in severe reproductive failure as well as a low to moderate incidence of larval deformity. One razorback sucker muscle plug sample, collected near Four Corners, New Mexico (11 µg/g DW), was within the selenium concentration range (10 - 20 µg/g DW) associated with teratogenesis to sensitive species of fish (Lemly 1996, USDOI 1998).

If selenium concentrations in the eggs of Colorado pikeminnow were four times the concentrations in muscle tissues (2.9 to 3.9 µg/g DW) as reported by Buhl and Hamilton (1998), then reproductive impairment and larval deformity would be likely (assuming that the razorback sucker or pikeminnow are as sensitive to selenium as other sensitive species, such as bluegill or perch [Gillespie et al. 1988, USDOI 1998]). If the ratio for selenium accumulation from diet to reproductive tissue were one-to-one as Buhl and Hamilton (1998) have suggested, then selenium concentrations in pikeminnow reproductive tissue would be expected to be as high as those found in its potential prey. If their prey consisted of small fish (0.2-14.3 µg/g DW) there would likely be reproductive impairment, or if their prey consisted of sucker species from the mainstem (0.1-5.4 µg/g DW) the likelihood of reproductive impairment would be low. Empirical data on the selenium concentrations in the reproductive tissues of the endangered fish and the threshold of toxicity are clearly needed for the understanding and management of the risk to these species.

Colorado pikeminnow may also be influenced by elevated body burdens of selenium found in their diet. Osmundson et al. (in press) reported that fathead minnows, red shiners, and sand shiners were the primary dietary items of adult Colorado pikeminnow in the upper Colorado River. Of these fish species, only fathead minnows and red shiners were collected and analyzed from the San Juan River. In backwater habitats, red shiners have been shown to be sympatric with Colorado pikeminnow (Tyus 1991). Therefore, small fish, speckled dace, and especially red shiners should be considered as potential dietary items for Colorado pikeminnow in a risk assessment until studies determine the composition of prey taken by the pikeminnow in the San Juan River. All of these fish species were found to exceed the selenium dietary criterion (3.0 µg/g), proposed by Lemly (1993) to protect sensitive species of fish (and birds).

Dietary exposure to selenium was considered the primary mechanism of selenium accumulation and toxicity (Hamilton et al. 1990, Lemly 1996, Hamilton and Buhl 1995, 1997). McAda and Wydowski (1980) and Bestgen (1990) suggest that the diet of razorback sucker was composed primarily of "ooze," (i.e., detritus) and insect larvae, such as found in low-velocity habitats of the San Juan River. Potential dietary items of razorback sucker, such as invertebrates found at the mouths of tributaries and in irrigation drains, could likely pose some chronic reproductive risks and/or larval toxicity. Invertebrates sampled from all reaches exceed the dietary threshold (2.3 µg Se/g) proposed by Hamilton et al. (1996) for toxicity to larval razorback sucker. If copper and selenium were synergistically or additively toxic in the diet as found with water (Hamilton and Buhl 1995), then high concentrations of both selenium and copper in the diet may pose even an increased risk to razorback sucker. Therefore, some reproductive health risks are likely posed to razorback suckers, especially as they reside and feed extensively in areas of irrigation return and at the mouths of tributaries.

Lemly (1996a, 1996b) and the USDOI (1998) reported selenium concentrations in the bird diets greater than 3 µg/g DW are above the threshold of toxicity for sensitive species of birds, and concentrations above 50 µg/g DW were catastrophic. Two hundred and twenty-six samples of fish (37%), 51 invertebrate samples (59%), and two plant samples (4%) had selenium concentrations above the 3 µg/g DW toxicity threshold for bird diets.

Table 17. Comparison of San Juan River Selenium Concentrations (µg/g Dry Weight [DW]) in Plants, Invertebrates, and Fish with Ambient Concentrations and Thresholds of Concern.

Data Comparisons and Hazard Assessment

Sample Type	Ambient/Threshold Concentrations	San Juan River Results
Aquatic Plants	Ambient background[a]: <2 µg/g Sublethal effects[b]: > 4.0 µg/g	Range:<0.08-4.4 µg/g
Invertebrates	Ambient background[a]: <2 µg/g Range, sublethal effects[b]: 2.5-15 µg/g	Range:<0.1-18.0 µg/g
Whole Body Fish	Ambient background[c]: <2 µg/g Toxicity threshold[d]: >4 µg/g Teratogenesis range[b]: 10-20 µg/g	Range: 0.1-15.1 µg/g 67% fish >2 µg/g 19% fish >4 µg/g 2% fish >10 µg/g
Muscle Tissues	Reproductive failure[b,d]: 7 - 9 µg/g Lowest human health advisories[b]> 8 µg/g	Razorback: 1.1-11 µg/g Pikeminnow: 2.9-3.9 µg/g Flannelmouth: <0.1-3 µg/g
Endangered Fish Ovaries	Reproductive impairment[c]: 7-13 µg/g Deformities[d]: > 10 µg/g	No Data Available
Razorback Sucker Diet	Toxicity threshold razorback sucker[c]: 2.3 µg/g	periphyton:<0.2-4.4 µg/g invertebrates :<0.4-18 µg/g
C. pikeminnow and other Fish Diet	Fish dietary criterion[e]: 3.0 µg/g	suckers: 0.1-5.4 µg/g small fish: 0.2-14.3 µg/g
Bird Diet	Toxicity in sensitive species[e]:> 3.0 µg/g	37% fish >3.0 µg/g 59% inverts>3.0µg/g 3% plants >3.0 µg/g

Sites/River Reaches of Concern

Selenium concentrations were clearly elevated in all biota above ambient background concentrations. One plant sample, 45% of invertebrate samples, and 76% of fish samples (including one razorback sucker) had selenium concentrations above thresholds of concern. The majority of fish above these thresholds were smaller species (e.g., dace, minnows) and trouts from upstream river reaches. Robust methods to quantify and detect selenium toxicity involve the chemical analyses of egg/ovaries in conjunction with laboratory toxicity tests were not completed for endangered fish, or habitats of concern were insufficiently sampled (backwater habitats). Given selenium concentrations in other tissues or in diets, reproductive failure was expected to occur with a low-to-moderate occurrence.

[a]Maier & Knight 1994; [b]USDOI 1998,[c]Hamilton et al. 1998; [d]Lemly 1993, 1996a, 1996b,[e]LemlySmith 1987

Zinc

Data Comparisons
Zinc concentrations in biota ranged between 3.9 in plants and 421 µg/g DW in carp (Appendix A). The number of samples, geometric mean, and range of zinc concentrations are summarized by river reach, sample type, and fish species in Appendix E. The geometric mean zinc concentrations in submergent plants, invertebrates, and fish species are evaluated by river reach in Table 18. Summary findings regarding arsenic including data comparisons and a hazard assessment are found in Table 19.

Zinc concentrations in aquatic plants ranged between 3.9 and 402 µg/g DW. Concentrations of zinc in aquatic plants increased significantly below River Reach 7. Three aquatic plant samples were considered regionally elevated (i.e., they exceeded the calculated 95^{th} percentile RCM value for zinc; Figure 21). These samples were collected from below the confluence of the Animas River and from backwaters in River Reach 6. These backwaters received irrigation return flows indicating that zinc concentrations may also have been enriched by way of soil leachate. The USDOI (1998) reported a toxicity threshold of 300 µg/g DW that was exceeded by one periphyton sample collected below the confluence of the Animas River.

Concentrations of zinc in invertebrates ranged from 12 µg/g to 247 µg/g DW with the highest concentrations from River Reach 5 and River Reach 6 (downstream of the Animas River confluence). Four invertebrate samples were considered regionally elevated using the RCM. The invertebrates collected below the confluence with the Animas River contained the highest concentration (247 µg/g DW). Invertebrate samples were collected from River Reach 5, and from a backwater that received irrigation return flows in River Reach 6. Invertebrates from the San Juan River were within ambient zinc ranges reported by Eisler (1993).

Zinc concentrations in whole body fish ranged between 29.0 and 421 µg/g DW. The geometric mean concentrations of zinc in fish species were: common carp, 183.7 µg/g DW; small fish, 133.8 µg/g DW; flannelmouth suckers, 50.3 µg/g DW; and rainbow trout, 81.4 µg/g DW. Carp, small fish, and speckled dace had significantly higher concentrations of zinc than found in flannelmouth suckers and generally higher than found in bluehead suckers (Table 18). In the upper reaches, rainbow trout also accumulated significantly higher concentrations of zinc than in flannelmouth suckers. Higher concentrations of zinc in carp have been attributed to the accumulation of zinc in the scales of carp as well as species specific zinc requirements (Scmitt and Brumbagh 1990), which could explain the elevated zinc found in small fish samples and trout compared to those in flannelmouth suckers. Habitat and dietary preferences of trout or small fishes may also play a role in zinc accumulation in tissues compared with sucker species. No correlation was found with size.

Using the Regional Comparison Method, 15 whole body common carp samples were considered regionally elevated. The majority (8/15) were collected from River Reach 5 and River Reach 6 below the Animas River confluence, while the other samples were collected upstream of the Animas River or from the Lake Powell near Piute Farms, Utah. Zinc concentrations in sucker species (10-42 µg/g DW), trout species (16-37 µg/g DW), small fish (19-72 µg/g DW), and channel catfish (10-56 µg/g DW), (but not carp [15-290 µg/g DW]) were within the range reported by Eisler (1993) as background (98-122 µg/g DW) for fish from Nova Scotia. Fish from the San Juan River (10-290 µg/g WW) were above the 85th percentile value (46.3 µg/g WW) reported by Schmitt and Brumbagh (1990) in fish sampled nationwide (even with carp removed from the data analysis).

Irrigation in River Reach 3 through River Reach 6, and the activities of Farmington, New Mexico, could contribute zinc into the San Juan River environment, but the contribution of the Animas River may also have affected zinc accumulation rates in biota of these river reaches. Concentrations of zinc in water, sediment, and whole body fish from the Animas River and downstream were greater than those sampled in the San Juan River upstream of its confluence with the Animas River. Mean zinc concentrations in sediment from the San Juan River were 57.5 µg/g DW (n=13), while zinc concentrations in Animas River sediment were 415 µg/g DW (n=12) (USGS 1994, 1995, 1996, 1997; Abell 1994b). Ambient waterborne zinc in the San Juan River were 0.03 µg/L (n=13), while zinc concentrations in the Animas River were 0.10 µg/L (n=32) (Abell 1994b). Flannelmouth suckers collected from the San Juan River above the Animas River confluence (River Reach 7) had geometric mean zinc concentrations of 46.9 µg/g DW. Flannelmouth suckers collected from the Animas River confluence, and directly below, had a mean zinc concentration of 77.63 µg/g DW (n=8). Generally, concentrations of zinc in water, sediment, plants, invertebrates, and fish collected downstream or from the Animas River were elevated compared to zinc concentrations in water, sediment, and biota collected in the San Juan River upstream of the Animas River confluence. The Animas River seemed to contribute a zinc load to the San Juan River. However, this reach of the San Juan River also received waste waters, storm runoff, and irrigation return discharges too.

<u>Hazard Assessment</u>

The USDOI (1998) also reported a Level of Concern for zinc concentrations in plants that ranged from 150 to 300 µg/g DW. Two periphyton samples collected from irrigation drains in River Reach 6 and a periphyton sample collected below the confluence of the Animas River had concentrations of zinc within this range. The accumulation of zinc in these selected species of fish seemed to be related to scale accumulation, in the case of carp, or, in the case of the smaller fish, related to their physiology, habitat or dietary preferences. The USDOI (1998) did not report whole body zinc concentrations that would cause toxicity to invertebrates or fish. Zinc concentrations were within the nutritional range (150-200 µg/g DW) recommended for channel catfish rearing reported by Eisler (1997). Eisler (1993, 1997) reported that stunting could occur to ducklings that consumed a zinc-rich diet (>178 µg/g DW). High concentrations were found often in San Juan River carp samples and invertebrates collected downstream of the Animas River confluence.

Table 18. Geometric Mean of Zinc Concentrations (µg/g, Dry Weight) in Submergent Plants, Invertebrates, and Fish from River Reach 1 Through River Reach 8 of the San Juan River (See Figure 1).

River Reach / Sample Type	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	All Reaches
Submergent Plants	42.0		63.7 (8)*	65.3	83.3 (8)*	146.3 (7,8)*	40.8	22.4	41.9
Invertebrates	120.4	94.7	122.5	102.4	168.9 (8)*	153.7 (8)*	86.7	59.7	90.8
Whole Body Fish	94.9	83.3	94.6	92.5	79.7	69.9	87.2	92.7 (6)*	84.4
Fish Species									
Bluehead Sucker (BH)			53.6	71.2	45.8	48.4	56.0		50.9
Brown Trout (BT)							**$_{FM}$ 91.8	**$_{FM}$ 83.6	84.2
Common Carp (CC)	**$_{CF,FM,SF}$		**$_{BH,CF,FM}$ 159.9		**$_{BH,CF,FM}$ 197.5	**$_{BH,BT,FM}$ 193.5	**$_{BH,BT,FM,RT,SF}$ 263.8	**$_{BT,FM,RT}$ 146.1	183.7
Channel Catfish (CF)	96.6	84.9	55.3		*$_{FM}$ 66.1				73.4
Flannelmouth Sucker (FM)	62.0	56.7	63.9	57.0	44.3	48.0	46.9	41.7	50.3
Rainbow Trout (RT)							**$_{FM}$ 76.8	**$_{FM}$ 81.5	81.4
Small Fish (SF)	**$_{FM}$ 112.5	**$_{BH,FM}$ 130.5	**$_{BH,CF,FM}$ 133.9	**$_{FM}$ 161.5	**$_{BH,CF,FM}$ 135.7	**$_{BH,BT,FM}$ 172.6	**$_{BH,FM}$ 108.5	**$_{FM}$ 112.0	133.8
Speckled Dace (SD)			**$_{BH,CF,FM}$ 183.0	**$_{FM}$ 187.7		**$_{BH,FM}$ 134.6			164.1

* Samples from this river reach had significantly ($p \leq 0.05$) greater zinc concentrations than found in samples from the river reach indicated by superscript; identified using dry weight, natural log transformed concentrations without regard to species differences.

** Fish species (identified by species code on left) in that river reach had significantly ($p \leq 0.05$) greater zinc concentrations than found in other fish species indicated by subscript in that river reach; identified using dry weight, natural log transformed concentrations.

Figure 21. Plot of Zinc concentrations in Aquatic Plants.

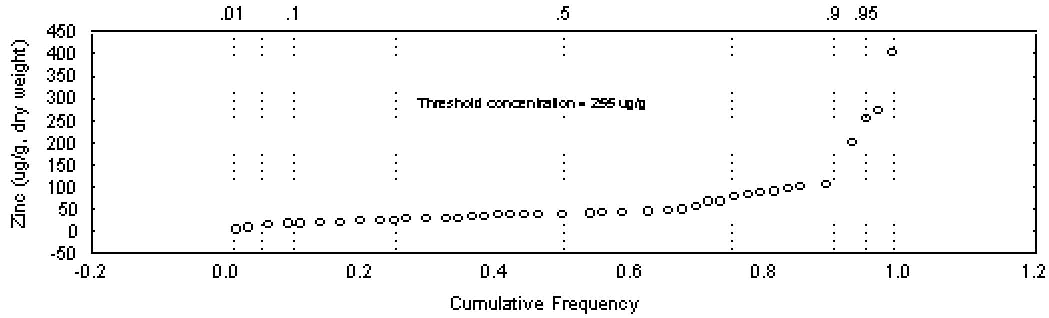


Figure 22. Plot of Zinc concentrations in Invertebrates.

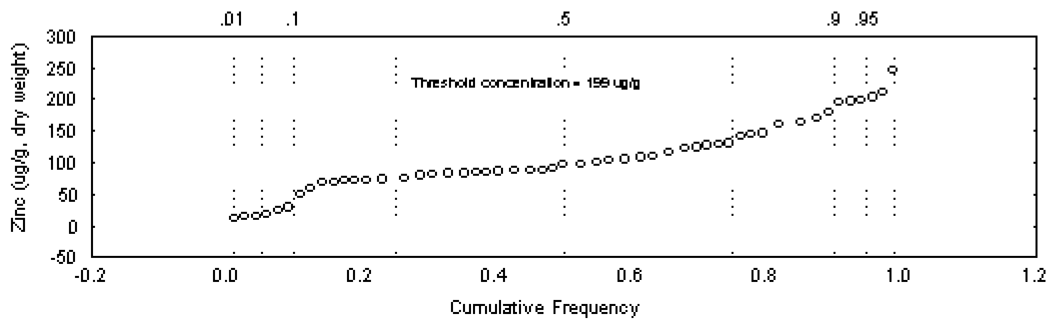
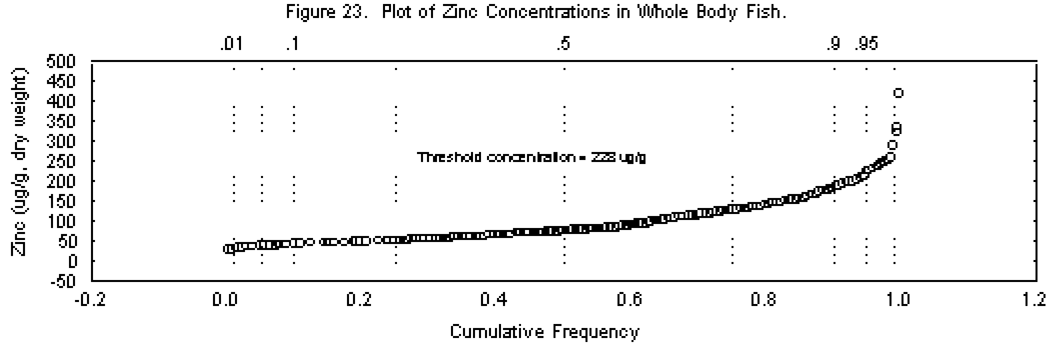


Figure 23. Plot of Zinc Concentrations in Whole Body Fish.



Figures 21, 22, and 23. Cumulative Frequency Distribution Plots of Zinc Concentrations (ug/g, dry weight) in Plants, Invertebrates, and Fish From the San Juan River, 1990-1996

Table 19. Comparison of San Juan River Zinc Concentrations (µg/g Dry Weight [DW] or Wet Weight [WW]) in Plants, Invertebrates, and Fish with Ambient Concentrations and Thresholds of Concern.

Data Comparisons and Hazard Assessment

Sample Type	**Ambient/Background Concentrations**	**San Juan River Results**
Aquatic Plants	No adverse effects threshold[a,b]:150 µg/g DW Level of Concern range[b]: 150-300 µg/g DW	Range: 3.9 - 402 µg/g DW 3 samples>300 µg/g DW
Invertebrates	Ambient ranges[c]: 104-506 µg/g DW	Invertebrates:12-247 µg/g DW
Whole Fish	Ambient range[c]: 98-122 µg/g DW NCBP range[d]: 34-46 µg/g WW	Fish (no carp):10-72µg/g WW Carp range:23-91µg/g WW
Bird Diet	Toxicity threshold[a,c]: > 178 µg/g DW	exceeded threshold: 8% of plants, 11% of invertebrates, 12% of fish

Sites/River Reaches of Concern

Zinc concentrations in plants, invertebrates, and whole body fish from River Reach 5 and River Reach 6 were generally higher than in biota from other river reaches. Species was the primary factor in zinc accumulation in fish. Carp and small fish had higher zinc concentrations than in other species of fish. The Animas River was a source of zinc to the San Juan River. Zinc concentrations were elevated and could contribute to stunting in sensitive species of birds.

[a] Eisler 1997; [b] USDOI 1998; [c] Eisler 1993; [d] Schmitt and Brumbagh 1990.

CONCLUSIONS

In 1991, the San Juan River Recovery Implementation Program (SJRIP) was initiated in order to recover endangered fish species in the San Juan River while accommodating water development. Studies of the San Juan River have identified contaminants of concern to be arsenic, copper, selenium, zinc, and PAHs. This study synthesized and evaluated environmental contaminant data collected on the San Juan River mainstem from 1990 to 1996. Data were evaluated to examine the effects of flows on contaminant residues in biota, to determine potential contaminant impacts to endangered fishes, and to evaluate contaminant trends in biota collected. Environmental contaminant data were collected in plants, invertebrates, and fish to examine the potential effects of contaminants on the recovery of endangered species, to identify areas of concern and their sources, and to guide the development of a long-term contaminant monitoring regime. Specifically, this study:

1) Analyzed environmental contaminant data for trends, contaminant sources, and assessed the potential hazards for the elements aluminum, arsenic, copper, mercury, selenium, and zinc. Polycyclic aromatic hydrocarbons, another potential contaminant, were discussed elsewhere (Wilson et al. 1995, Thomas et al. 1998, Wirth 1999);

2) Evaluated the relationship between environmental contaminant concentrations in aquatic plants, invertebrates, and whole body fish with flow regimes of the San Juan River mainstem and found no consistent correlations.

3) Assessed potential reproductive risks to Colorado pikeminnow and razorback sucker and identified contaminants (copper, selenium), prey items (invertebrates, small fish), and habitats (tributary mouths, irrigation drains) where environmental contaminants would pose concerns to these fishes' recovery. Tissues where selenium is toxic (ovaries) were not collected and definitive thresholds of concern for these fishes were not available. A risk assessment was performed on the data available that indicated reproductive failure could occur at a low-to-moderate occurrence. At least one razorback sample (of three sampled) was expected to produce deformed larvae or experience reproductive failure.

Unfortunately, sampling of backwater habitats was not extensive, even though these areas were important staging and feeding grounds for razorback sucker and Colorado pikeminnow. This oversight also limited the ability of this study to quantify the potential hazards to endangered fishes. To quantify the toxicity of selenium and copper in the diet and preferred habitats of the San Juan River fishes, additional information would be needed regarding the concentrations in their ovaries, diets, and sufficient data to identify concentrations in muscle plugs (a nonlethal sampling method) that are related to any adverse reproductive effects.

Aluminum accumulation in biota seemed to be associated with sediment geochemistry. Biota collected from River Reach 8, a cooler, less turbid stream reach downstream of Navajo Dam contained less aluminum than in biota from downstream, more turbid river reaches. Animals closely associated with sediment, including algae, aquatic worms, and benthic fish species had aluminum concentrations considered regionally elevated. If aluminum concentrations were bioavailable, or if the environment becomes more acidic, and calcium or phosphorus were unavailable, then herbivorous and omnivorous birds might experience adverse effects such as reduced growth and altered metabolism.

Elevated arsenic concentrations were found in most submergent plants and in five percent of the fish analyzed. Arsenic concentrations in plants exceeded concentrations considered phytotoxic to other plant species and could occur. Arsenic was elevated in some invertebrate and whole fish samples. No consistent pattern of arsenic accumulation was identified for any river reach or site. Toxicity of arsenic often depends on its chemical form, route of exposure, and species sensitivity, which were not evaluated in this study. Arsenic concentrations were below the threshold of concern for duckling growth and other avian levels of concern.

Elevated copper in invertebrates may have augmented body burdens of copper in insectivorous trouts collected from the upstream coldwater river reaches. With trouts removed from the data, plants, invertebrates, and whole fish all show increased copper concentrations as they were collected downstream. As copper concentrations increased in invertebrates in the lower river reaches, insectivorous fish species, perhaps including the resident razorback sucker, would also be exposed to elevated copper in their diet potentially resulting in elevated body burdens or reduced growth and larval survival. Copper was not likely to pose a health risk to waterfowl.

Selenium concentrations were clearly elevated in all biota above ambient background concentrations. One plant sample, 45% of invertebrate samples, and 76% of fish samples (including one razorback sucker) had selenium concentrations above thresholds of concern. The majority of fish above these thresholds were smaller species (e.g., dace, minnows) and trouts from upstream river reaches. Robust methods to quantify and detect selenium toxicity involve the chemical analyses of egg/ovaries in conjunction with laboratory toxicity tests. Laboratory tests were not completed (for endangered fish) and essential habitats were insufficiently sampled to make conclusions necessary for a quantitative assessment. Given selenium concentrations in other tissues or in diets, reproductive failure by these endangered fish was expected to occur with a low-to-moderate occurrence.

Zinc concentrations in plants, invertebrates, and whole body fish from River Reach 5 and River Reach 6 were generally higher than in biota from other river reaches. Species was the primary factor in zinc accumulation in fish. Carp and small fish had higher zinc concentrations than in other species of fish. The Animas River was indicated as a source of zinc to the San Juan River. Zinc concentrations were elevated in biota and could contribute to stunting in sensitive species of birds.

RECOMMENDATIONS

1. Navajo Dam Operations for the Recovery and Conservation of San Juan River Endangered Fish Need Not be Based on Concentrations of Contaminants in Biota

The findings of this study indicate that the concentrations of contaminants in biota inhabiting the mainstem of the San Juan River were not consistently correlated with instream flow discharges. Therefore, incorporating a contaminant-related component into the flow recommendation for recovery of San Juan River endangered fish is not advised. However, variations in off-channel wetland quality that may affect exposure to larval and juvenile endangered fish, ultraviolet light penetration, as well as contaminant uptake by plants, aquatic invertebrates, and small fish may be indirectly linked to river dynamic processes, but were not addressed by this study.

2. Develop "Safe-Level" Reference Diets for Colorado Pikeminnow and Razorback Sucker

Research should be continued to determine the dietary threshold concentrations for selenium and copper that were elevated in the food items that pose risks to the endangered fishes. A factor for the conversion of concentrations of selenium in muscle plugs (a nonlethal monitoring method) with concentrations in ovaries known to cause reproductive toxicity should be determined. A long-term monitoring regime could then include the collection of muscle plugs (and ultimately, other less invasive techniques) in order to identify concerns in endangered fish.

Any long-term monitoring program must have clear data quality objectives specific to the recovery of endangered fishes. Monitoring of copper, selenium, and PAHs at potential spawning and staging sites of endangered fish should be considered and the study design robust enough to determine significant changes in their environment. A long-term monitoring program for endangered fishes in the San Juan River based upon surrogate species should be mindful of species-specific patterns of contaminant accumulation. For example, while flannelmouth suckers may be an excellent phylogenetic surrogate for razorback suckers, they were not an adequate toxicological surrogate. Patterns of selenium accumulation in muscle (and likely ovaries) between the two species would vary considerably even in similar environments. The mechanisms of selenium uptake, accumulation, and likely effects between the two species would be quite different. Direct, nonlethal measurement of contaminant concentrations in endangered species was recommended in order to reduce species-to-species uncertainty.

LITERATURE CITED

Abell, Robin. 1994a. San Juan River Basin Water Quality and Contaminants Review. Volume I, Museum of Southwestern Biology, University of New Mexico, Albuquerque, New Mexico.

Abell, Robin. 1994b. San Juan River Basin Water Quality and Contaminants Review. Volume II, Museum of Southwestern Biology, University of New Mexico, Albuquerque, New Mexico.

Allen, K. N. 1991. Seasonal Variation of Selenium in Outdoor Experimental Stream-Wetland Systems. Journal of Environmental Quality 20:865-868.

Allert, A.L., K.R. Echols, S.E. Finger, R.W. Gale, E.E. Little, T.W. May, T. Thorn, and E.V. Callahan. 1999. Effects of Environmental Perturbations on the Aquatic Community in the San Juan River. U.S. Geological Survey Final Report to the Bureau of Land Management, Columbia, Missouri.

American Geological Institute. 1984. Dictionary of Geological Terms, eds., R.L. Bates and A. Jackson. New York: Doubleday Anchor Books.

Bailey, N.J.J. 1981. Statistical Methods in Biology. Second Edition. Cambridge University Press. New York, New York.

Bestgen, K.R. 1990. Status Review of the Razorback Sucker, *Xyrauchen Texanus*. Contribution 44, Colorado State University Larval Fish Laboratory.

Beyer, W. N., and G. Linder. 1995. Making Sense of Soil Ecotoxicology. Pages 104-116 in, D. J. Hoffman, B.A. Rattner, G. A. Burton, and J. Cairns (Eds.), Handbook of Ecotoxicology. Lewis Publishers, CRC Press, Boca Raton, Florida.

Blanchard, P.J., R.R. Roy, and T.F. O'Brien. 1993. Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated With Irrigation Drainage in the San Juan River Area, San Juan County, Northwestern New Mexico, 1990-91. U.S. Geological Survey Water-Resources Investigations Report 93-4065.

Bliesner, R., and V. Lamarra. 1993. San Juan River Habitat Studies - 1992 Annual Report. Keller Bliesner Engineering, Logan, Utah, and Ecosystems Research Institute, Logan, Utah.

Bliesner, R., and V. Lamarra. 1994. San Juan River Habitat Studies - 1993 Annual Report. Keller Bliesner Engineering, Logan, Utah, and Ecosystems Research Institute, Logan, Utah.

Bliesner, R., and V. Lamarra. 1995. San Juan River Habitat Studies - 1994 Annual Report. Keller Bliesner Engineering, Logan, Utah, and Ecosystems Research Institute, Logan, Utah.

Buhl, K.J. and S.J. Hamilton. 1998. *Draft* Document for The Chronic Toxicity of Dietary and Waterborne Selenium to Adult Colorado Squawfish (*Ptychocheilus lucius*) in a Water Quality Simulating that in the San Juan River. U.S. Geological Survey, Environmental and Contaminants Research Center, Yankton, South Dakota.

Bullock, K.C. 1960. Minerals and Mineral Localities of Utah. (Publisher information unavailable, cited in Abell 1994)

Camardese, M.B., Hoffman, D.J., LeCaptain, L.J., and G.W. Pendleton. 1990. Effects of Arsenate on Growth and Physiology in Mallard Ducklings: Environmental Toxicology and Chemistry, v. 9, p. 785-795.

Carter, L.F. 1997. Water-Quality Assessment of the Rio Grande Valley, Colorado, New Mexico, and Texas - Organic Compounds and Trace Elements in Bed Sediment and Fish Tissue, 1992-93. U.S. Geological Survey Water-Resources Investigations Report 97-4002.

Cleveland , L., E.E. Little, D.R. Buckler, and R.H. Wiedmeyer. 1993. Toxicity and Bioaccumulation of Waterborne and Dietary Selenium in Juvenile Bluegill (*Lepomis Macrochirus*). Aquatic Toxicology 27: 265-280.

Cockell, K.A., J.W. Hilton, and W.J. Bettger. 1991. Chronic Toxicity of Dietary Disodium Arsenate Heptahydrate to Juvenile Rainbow Trout (*Onchorynchus mykiss*). Archives of Environmental Contamination and Toxicology 21: 518-527.

Coughlan, D.J. and J.S. Velte. 1989. Dietary Toxicity of Selenium-Contaminated Red Shiners to Striped Bass. Transactions of the American Fishery Society 118:400-408.

Decamps, H., and O. Decamps. 1989. River Ecosystems: Ecological Concepts and Dynamics. Pages 3-20 in A. Boudou and F. Ribeyre (eds.) Aquatic Ecotoxicolgy: Fundamental Concepts and Methodologies, Volume I. CRC Press, Boca Raton, Florida, USA. 332 pp.

Eisler, R. 1985. Selenium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85(1.5). 57 pp.

Eisler, R. 1987. Mercury Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 85 (1.10). 90 pp.

Eisler, R. 1994. A Review of Arsenic Hazards to Plants and Animals with Emphasis on Fishery and Wildlife Resources. Pages 185-259 in J.O. Nriagu (Ed.), Advances in Environmental Science and Technology. John Wiley and Sons.

Eisler, R. 1993. Zinc Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service Biological Report 10. 106 pp.

Eisler, R. 1997. Zinc Hazards to Plants and Animals with Emphasis on Fishery and Wildlife Resources, *in* Ecological Issues and Environmental Impact Assessment, ed., P.N. Cheremisinoff. Houston:Gulf Publishing Company, Advances in Environmental Control Technology Series. pp. 443-457.

Eisler, R. 1998. Copper Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Geological Survey, Biological Research Division, Contaminant Hazard Reviews Report 33. 98 pp.

Engberg, R.A. 1998. Selenium Budget for Lake Powell, Upper Colorado River Basin, Western United States. Proceedings of the Sixth International Symposium on the Uses of Selenium and Tellerium, Scottsdale, Arizona.

Environment Ontario. 1984. Water Management: Goals, Policies, Objectives, and Implementation Procedures of the Ministry of Environment. Ontario, Canada. 70 pp.

Farag, A.M., C.J. Boese, D.F. Woodward, and H.L. Bergman. 1994. Physiological Changes and Tissue Metal Accumulation in Rainbow Trout Exposed to Foodborne and Waterborne Metals. *Environmental Toxicology and Chemistry*, Vol. 13, No. 12, pp. 2021-2029.

Finley, K.A. 1985. Observations of Bluegills Fed Selenium-Contaminated *Hexagenia* Nymphs collected from Belews Lake, North Carolina. *Bulletin of Environmental Contamination and Toxicology.* 35:816-825.

Gillespie, R.B, P.C. Baumann, and C.T. Singley. 1988. Dietary Exposure of Bluegills (*Lepomis Macrochirus*) to (75) Se: Uptake and Distribution in Organs and Tissues. *Bulletin Environmental Contamination Toxicology.,* Vol. 40, pp. 771-778.

Hamilton, S.J., K.J. Buhl, N.L. Faerber, R.H. Wiedmeyer, and F.A. Bullard. 1990. Toxicity of Organic Selenium in the Diet to Chinook Salmon. Environmental Toxicology and Chemistry, Vol. 9, pp. 347-358.

Hamilton, S.J. and B. Waddell. 1994. Selenium in Eggs and Milt of Razorback Sucker (*Xyrauchen texanus*) in the Middle Green River, Utah. *Arch. Environmental Contamination and Toxicology.* 27, 195-201.

Hamilton, S.J., K.J. Buhl, F.A. Bullard, and S.F. McDonald. 1996. Evaluation of Toxicity to Larval Razorback Sucker of Selenium-Laden Food Organisms from Ouray NWR on the Green River, Utah. National Biological Service, Midwest Science Center, Ecotoxicology Research Station.

Hamilton, S.J. and K.J. Buhl. 1995. Hazard Assessment of Inorganics, Individually and in Mixtures, to Two Endangered Fish in the San Juan River, New Mexico. *Environmental Toxicology. Water. Quality.* **12**:195-209.

Hamilton, S.J. and K.J. Buhl. 1997. Hazard Evaluation of Inorganics, Singly and in Mixtures, to Flannelmouth Sucker *Catostomus latipinnis* in the San Juan River, New Mexico. *Ecotoxicology and Environmental Safety* 38:296-308.

Hamilton, S.J., R.T. Muth, B. Waddell, and T.W. May. 1998. Selenium and Other Trace Elements in Wild Larval Razorback Suckers from the Green River, Utah. Final Report to the National Irrigation Water Quality Program, Denver, Colorado. (accepted for publication in Ecotoxicology an Environmental Safety, 2000).

Hamilton, S.J., K.J. Buhl, F.A. Bullard, and E.E. Little. (2000). Chronic Toxicity and Hazard Assessment of an Inorganic Mixture Simulating Irrigation Drainwater to Razorback Sucker and Bonytail. Environmental Toxicology 15: (i*n press*).

Hilton, J.W., Hodson, P.V., and Sliniger, S.J. 1980. The Requirement and Toxicity of Selenium in Rainbow Trout (Salmo Gairdneri): The Journal of Nutrition, v. 110, p. 2527-2535.

Hodson, P.V., D.J. Spry, and B.R. Blunt. 1980. Effects on Rainbow Trout (Salmo Gairdneri) of a Chronic Exposure to Waterborne Selenium. Can. J. Fish. Aquat. Sci., 37:233-240.

Hodson, P. V., and J. W. Hilton. 1983. The Nutritional Requirements and Toxicity to Fish of Dietary and Waterborne Selenium. Environmental Biogeochemistry and Ecology Bulletin (Stockholm) 35:335-340.

Hoffman, D.J., C.P. Rice, and T. Kubiak. 1996. PCBs and Dioxins in Birds. Pages 165-207 In Beyer, W.N., Heinz, G.H., and Redmon-Norwood, A.W. (Eds.), Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations. Lewis Publishers, Boca Raton, Florida.

Holden, P. B., R. D. Hugie, L. Crist, S. B. Chanson, and W. J. Masslich. 1986. Development of a Fish and Wildlife Classification System for Backwaters Along the Lower Colorado River. Final Report for Bureau of Reclamation, Bio/West Inc., Logan, Utah. 207 pp.

Holden, P.B. 1998. Flow Recommendations for the San Juan River. Predraft Report prepared by the San Juan River Recovery Implementation Program Biology Committee.

Holden, P.B. (Editor). 1999. Flow Recommendations for the San Juan River. San Juan River Basin Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Huckabee, J.W., J.W. Elwood, and S.G. Hildebrand. 1979. Accumulation of Mercury in Freshwater Biota, *in* The Biogeochemistry of Mercury in the Environment., ed., J.O. Nriagu. New York: Elsevier/North-Holland Biomedical Press. pp. 277-302.

Jenkins, D.W. 1980. Biological Monitoring of Trace Metals. U.S. Environmental Protection Agency Rep. 600/3-80-091. pp. 619-778.

Kane, D.A. and C.F. Rabeni. 1987. Effects of Aluminum and pH on the Early Life Stages of Smallmouth Bass (*Micropterus dolomieui*). *Water Res*., Vol. 21, No. 6, pp. 633-639.

Keller-Bliesner Engineering and Ecosystems Research Institute. 1991. Navajo Indian Irrigation Project Blocks 1-8, Biological Assessment: Water Quality Analysis Section. Keller-Bliesner Engineering and Ecosystems Research Institute, Logan, Utah.

Keller-Bliesner Engineering and Ecosystems Research Institute. 1999. Navajo Indian Irrigation Project Biological Assessment. Keller-Bliesner Engineering and Ecosystems Research Institute, Logan, Utah.

Kennnedy, D. M. 1979. Ecological Investigations of Backwaters Along the Lower Colorado River. Ph.D. Dissertation, University of Arizona, Tucson, AZ. 219 pp.

Lemly, A.D. 1993. Guidelines for Evaluating Selenium from Aquatic Monitoring and Assessment Studies. Environ. Monitor. Assess., 28:83-100.

Lemly, A.D. 1996a. Assessing the Toxic Threat of Selenium to Fish and Aquatic Birds. Environmental Monitoring. Assessments, 43:19-35.

Lemly, A.D. 1996b. Selenium in Aquatic Organisms. Pages 427-445 In W.N.Beyer, G.H. Heinz, and A.W. Redmon, (Eds.), Interpreting Environmental Contaminants in Animal Tissues. Lewis Publishers, Boca Raton, Florida.

Maier, K.J. and A.W. Knight. 1994. Ecotoxicology of Selenium in Freshwater Systems. Reviews of Environmental Contamination and Toxicology, 134:31-48.

McAda, C.W. and R.W. Wydowski. 1980. The Razorback Sucker, *Xyrauchen Texanus*, in the Upper Colorado River Basin, 1974-1976. U.S. Fish and Wildlife Service Technical Paper pp. 99.

Miller, W.J. 1995. San Juan River Colorado Squawfish Habitat Use. 1994 Annual Report Submitted to the San Juan River Recovery Implementation Program.

Montana, A., R. Crespi, and G. Liborio. 1993. Simon and Schuster's Guide to Rocks and Minerals, eds., M. Prinz, G. Harlow, and J. Peters. New York: Simon and Schuster.

Namminga, H. and J. Wilhm. 1977. Heavy Metals in Water, Sediments, and Chironomids. Journal of the Water Pollution Control Federation. pp. 1725-1731.

National Research Council. 1980. Mineral Tolerance of Domestic Animals. National Academy Press, National Academy of Sciences, Washington, District of Columbia 577 pp.

O'Brien, T. 1987. Organochlorine and Heavy Metal Contaminant Investigation of the San Juan River Basin, New Mexico, 1984. U.S. Fish and Wildlife Service, Ecological Services Field Office, Albuquerque, New Mexico.

Odell, S. 1997. 1996 Annual Report on Data Collection Activities Concerning Suspected Contributions of Polynuclear Aromatic Hydrocarbons by Oil and Gas Leasing on Public Lands in the San Juan Basin, New Mexico. Bureau of Land Management, Farmington District Office, Farmington, New Mexico.

Ogle, R.S. and A.W. Knight. 1989. Effects of Elevated Foodborne Selenium on Growth and Reproduction of the Fathead Minnow (*Pimephales Promelas*). Archives of Environmental Contamination and Toxicology 18: 795-803.

Ohlendorf, H.M. 1989. Bioaccumulation and Effects of Selenium in Wildlife, *in* Selenium in Agriculture and the Environment. Madison: SSSA Special Publication No. 23.

Ohmart, R. D., B. W. Anderson, and W. C. Hunter. 1988. The Ecology of the Lower Colorado River from Davis Dam to the Mexico-United States International Boundary: A Community Profile. U.S. Fish and Wildlife Service Biological Report 85(7.19). 296 pp.

Osmundsen, D.B. 1998. Dispersal Patterns of Sub-adult and Adult Colorado Squawfish in the Upper Colorado River. Transactions of the American Fishery Society. (In press)

Pais, I., and J.B. Jones. 1997. The Handbook of Trace Elements. CRC Press, Inc., Boca Raton, Florida.

Peterson, J.A. and A.V. Nebeker. 1992. Estimation of Waterborne Selenium Concentrations that were Toxicity Thresholds for Wildlife. Archives of Environmental Contamination and Toxicology 23:154-162.

Presser, T.S. 1994. The Kesterson Effect. Environmental Management 18(3):437-454.

Propst, D.L. and A.L. Hobbes. 1995. Icthyological Characterization of San Juan River Secondary Channels. 1994 Annual Progress Report submitted to the San Juan River Recovery Implementation Program.

Richins, R.T. and A.C. Risser, Jr. 1975. Total Mercury in Water Sediment, and Selected Aquatic Organisms, Carson River–1972. Pesticides Monitoring Journal, Vol.9, No. 1.

Ryden, D. 1995a. Adult Fish Community Monitoring on the San Juan River. 1994 Annual Progress Report Submitted to the San Juan River Recovery Implementation Program.

Ryden, D. 1995b. Monitoring of Experimentally Stocked Razorback Sucker in the San Juan River. 1994 Annual Progress Report Submitted to the San Juan River Recovery Implementation Program.

Saiki, M.K. 1985. A Field Example of Selenium Contamination in an Aquatic Food Chain. From the Proceedings of the First Annual Environmental Symposium: Selenium in the Environment, June 10-12, Fresno, California.

Saiki, M.K. and T.P. Lowe. 1987. Selenium in Aquatic Organisms from Subsurface Agricultural Drainage Water, San Joaquin Valley, California. Transactions of the American Fishery Society 16: 657-670.

San Juan River Recovery Implementation Program Biology Committee. 1994. Seven Year Research Program Budget and Work Plan, Fiscal Year 1994. Prepared for the San Juan River Recovery Implementation Program Coordination Committee.

San Juan River Recovery Implementation Program Biology Committee. 1995. Seven Year Research Program Budget and Work Plan, Fiscal Year 1995. Prepared for the San Juan River Recovery Implementation Program Coordination Committee.

Schmitt, C.J. and W.B. Brumbaugh. 1990. National Contaminant Biomonitoring Program: Concentrations of Arsenic, Cadmium, Copper, Lead, Mercury, Selenium, and Zinc in U.S. Freshwater Fish, 1976-1984. Archives of Environmental Contamination and Toxicology 19:731-747.

Scheuhammer A.M. 1987. The Chronic Toxicity of Mercury, Cadmium, and Lead in Birds: a Review. Environmental Pollution: 46, 263-95.

Schultz, R., and R.Hermanutz. 1990. Transfer of Toxic Conentrations of Selenium from Parent to Progeny in the Fatehead Minnow (*Pimephales Promelas*). Bulletin of Environmental Contamination and Toxicology 45: 568-573.

Smith, T.R. and T.A. Haines. 1995. Mortality, Growth, Swimming Activity and Gill Morphology of Brook Trout (*Salvelinus fontinalis*) and Atlantic Salmon (*Salmo salar*) Exposed to low pH With and Without Aluminum. Environmental Pollution 90:33-40.

Sparling, D.W. and T.P. Lowe. 1996. Environmental Hazards of Aluminum to Plants, Invertebrates, Fish, and Wildlife. Reviews of Environmental Contamination and Toxicology, Vol. 145.

Standiford, D.L., L.D. Potter, and D.E. Kidd. 1973. Mercury in the Lake Powell Ecosystem. Lake Powell Research Project Bulletin No. 1. University of New Mexico, Albuquerque, New Mexico.

Stafford, C.P. and T.A. Haines. 1997. Mercury Concentrations in Maine Sport Fishes. Transactions of the American Fishery Society 126:144-152.

StatSoft, Inc. 1994. Statistica Volumes I: General Conventions & Statistics I. StatSoft, Inc., Tulsa, Oklahoma. 1718 p.

Stumm, W., and J. J. Morgan. 1970. Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria In Natural Waters. John Wiley and Sons, Inc, New York, USA. 583 pp.

Thomas, C.L., J.D. Lusk, R.S. Bristol, R.M. Wilson, and A.R. Shineman. 1997. Physical, Chemical, and Biological Data for Detailed Study of Irrigation Drainage in the San Juan River Area, New Mexico, 1993- 1994, with supplemental data, 1991-95. U.S. Geological Survey Open-File Report 97-249.

Thomas, C.L., R.M. Wilson, J.D. Lusk, R.S. Bristol, and A.R. Shineman. 1998. Detailed Study of Selenium and Selected Constituents in Water, Bottom Sediment, Soil, and Biota Associated with Irrigation Drainage in the San Juan River Area, New Mexico, 1991-1995. U.S. Geological Survey Water-Resources Investigations Report 98-4096.

Tyus, H.M. 1991. Movements and Habitat Use of Young Colorado Squawfish in the Green River, Utah. Journal of Freshwater Ecology, Vol. 6, No. 1, pp. 43-51.

United States Department of the Interior (USDOI). 1973. A Biologist's Manual for the Evaluation of Impacts of Coal-Fired Power Plants on Fish, Wildlife, and their Habitats. Fish and Wildlife Service FWS/OBS-78/75, Washington, D.C.

United States Department of the Interior (USDOI). 1998. Guidelines for the Interpretation of the Biological Effects of Selected Constituents in Biota, Water, and Sediment. USDOI National Irrigation Water Quality Program Information Report No. 3.

United States Environmental Protection Agency (USEPA). 1997. Mercury Study Report to Congress, Volume VI, An Ecological Assessment for Anthropogenic Mercury Emissions in the United States. December 1997. EPA-425/R-97-008. Washington, D.C.

United States Environmental Protection Agency (USEPA). 1998. Guidance for Data Quality Assessment: Practical Methods for Data Analysis: EPA QA/G-9 QA97 Version. EPA/600/R-96/084. Washington, D.C.

United States Geological Survey (USGS). 1994. Water Resources Data New Mexico Water Year 1994. U.S. Geological Survey Water-Data Report NM-94-1.

1995. Water Resources Data New Mexico Water Year 1995. U.S. Geological Survey Water-Data Report NM-95-1.

1996. Water Resources Data New Mexico Water Year 1996. U.S. Geological Survey Water-Data Report NM-96-1.

1997. Water Resources Data New Mexico Water Year 1997. U.S. Geological Survey Water-Data Report NM-97-1.

Utah Division of Water Quality. 1992. Storet Database: Water Quality Exceedence Report, October 1, 1988 to September 30, 1991.

Van Hattum, B., K.R. Timmermans, and H.A. Govers. 1991. Abiotic and Biotic Factors Influencing *in situ* Trace Metal Levels in Macroinvertebrates in Freshwater Ecosystems. Environmental Toxicology and Chemistry: 10: 275-292.

Velz, E.J. 1984. Applied Stream Sanitation (2nd Edition). New York, John Wiley and Sons.

Waddell, B. and T. May. 1995. Selenium Concentrations in the Razorback Sucker (*Xyrauchen texanus*): Substitution of Non-Lethal Muscle Plugs for Muscle Tissue in Contaminant Assessment. Archives of Environmental Contamination and Toxicology 28: 321-326.

Walter, C.M., F.C. June, and H.G. Brown. 1973. Mercury in Fish, Sediments, and Water in Lake Oahe, South Dakota. Journal of the Water Pollution Control Federation 45. No. 10.

Wilson, R.M., J.D. Lusk, S. Bristol, B. Waddell, and C. Wiens. 1995. Environmental Contaminants in Biota from The San Juan River and Selected Tributaries in Colorado, New Mexico, Utah. 1995 Annual progress report submitted to the San Juan River Recovery Implementation Program.

Wirth, D. 1999. Annual Report on Collection Activities for 1997 and 1998 Concerning Suspected Contributions of Polynuclear Aromatic Hydrocarbons by Oil and Gas Leasing on Public Lands in the San Juan Basin, New Mexico. Bureau of Land Management, Farmington Field Office, Farmington, New Mexico.